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# PREDICTION OF SUBSOIL ERODIBILITY USING CHEMICAL, MINERALOGICAL AND PHYSICAL PARAMETERS

Purdue University

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This report presents evidence that the surface soil erodibility prediction nomograph (Wischmeier et al., 1971) which uses terms involving soil particle size, organic matter, structure and permeability, could not be improved upon by consideration of other mineralogical and chemical parameters. However, the surface soil erodibility nomograph did not adequately predict the soil erodibility factor, K, of high clay subsoils studied in the field under simulated rainfall conditions as a part of this project. A multiple linear regression equation and nomograph were developed which can be used to estimate the erodibility factor, K, of many high clay subsoils. The subsoil erodibility nomograph uses terms involving soil particle size distribution and the amount of amorphous hydrous oxides or iron, aluminum, and silicon in the soil. Multiple regression analysis revealed that amorphous iron, aluminum and silicon hydrous oxides serve as soil stabilizers in subsoils, whereas, organic matter is the major stabilizer in surface soils.

Evidence is presented to show that soil erodibility from semi-compacted fill and scalped subsoil surface conditions were essentially identical. It is reported that the scalped condition is the best standard soil surface to base the calculation of the erodibility factor for subsoils.

It is suggested that a soil-management factor should replace the cropping-management factor in the Universal-Soil-Loss Equation when the Equation is used to predict subsoil erosion.

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# PREDICTION OF SUBSOIL ERODIBILITY USING CHEMICAL, MINERALOGICAL AND PHYSICAL PARAMETERS

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# ABSTRACT

This report presents evidence that the surface soil erodibility prediction nomograph (Wischmeier et al., 1971) which uses terms involving soil particle size, organic matter, structure and permeability, could not be improved upon by consideration of other mineralogical and chemical parameters. However, the surface soil erodibility nomograph did not adequately predict the soil erodibility factor, K, of high clay subsoils studied in the field under simulated rainfall conditions as a part of this project. A multiple linear regression equation and nomograph were developed which can be used to estimate the erodibility factor, K, of many high clay subsoils. The subsoil erodibility nomograph uses terms involving soil particle size distribution and the amount of amorphous hydrous oxides of iron, aluminum, and silicon in the soil. Multiple regression analysis revealed that amorphous iron, aluminum and silicon hydrous oxides serve as soil stabilizers in subsoils, whereas, organic matter is the major stabilizer in surface soils.

Evidence is presented to show that soil erodibility from semi-compacted fill and scalped subsoil surface conditions were essentially identical. It is reported that the scalped condition is the best standard soil surface to base the calculation of the erodibility factor for subsoils.

It is suggested that a soil-management factor should replace the cropping-management factor in the Universal Soil-Loss Equation when the Equation is used to predict subsoil erosion.

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## CONTENTS

Page

Abstract . . . . . . . . . . . . . . . . . . . . . . . . . ii

List of Figures . . . . . . . . . . . . . . . . . . . . . . iv

List of Tables . . . . . . . . . . . . . . . . . . . . . . ix

Acknowledgments . . . . . . . . . . . . . . . . . . . . . . xi

Sections

I Conclusions . . . . . . . . . . . . . . . . . . . . 1

II Recommendations . . . . . . . . . . . . . . . . . . 2

III Introduction . . . . . . . . . . . . . . . . . . . 3

IV Field Experiments . . . . . . . . . . . . . . . . . 6

V Laboratory Characterization of Reference Soils for Physical, Chemical, and Mineralogical Properties . . . . . . . . . . . . . . . . . . . . 54

VI Statistical Analysis of Data Obtained in Field and Laboratory Experiments . . . . . . . . . . . . 65

VII A Nomograph for Estimating the Erodibility Factor, K, of High Clay Subsoils . . . . . . . . . 74

VIII References . . . . . . . . . . . . . . . . . . . . 80

IX Appendices . . . . . . . . . . . . . . . . . . . . 82

## FIGURES

| No. | | Page |
|---|---|---|
| 1 | Plot view of the semi-compacted fill treatment on the McGary subsoil before rainstorm tests | 18 |
| 2 | Plot view of the scalped treatment on the McGary subsoil before rainstorm tests | 18 |
| 3 | Plot view of the tilled treatment on the McGary subsoil before rainstorm tests | 18 |
| 4 | Close-up view of the semi-compacted fill treatment on McGary subsoil before rainstorm tests | 19 |
| 5 | Close-up view of scalped treatment on McGary subsoil before rainstorm tests | 19 |
| 6 | Close-up view of tilled treatment on the McGary subsoil before rainstorm tests | 19 |
| 7 | Surface condition of tilled treatment on McGary subsoil after 63.5 mm (2.5 inches) of artificial rain | 20 |
| 8 | Close-up view of scalped treatment on Portageville subsoil after 127mm (5 inches) of artificial rain | 20 |
| 9 | Close-up view of tilled treatment on Portageville subsoil after 127mm (5 inches) of artificial rain | 22 |
| 10 | Plot view of tilled treatment on Portageville subsoil after 127mm (5 inches) of artificial rain | 22 |
| 11 | Plot view of scalped treatment on Portageville subsoil after 127mm (5 inches) of artificial rain | 22 |
| 12 | Plot view of scalped treatment on St. Clair subsoil before rainstorm tests | 23 |
| 13 | Plot view of tilled treatment on St. Clair subsoil before rainstorm tests | 23 |

FIGURES (continued)

| No. | | Page |
|---|---|---|
| 14 | Plot view of semi-compacted fill treatment on St. Clair subsoil before rainstorm tests | 23 |
| 15 | Close-up view of the scalped treatment on St. Clair subsoil before rainstorm tests | 24 |
| 16 | Close-up view of the tilled treatment on St. Clair subsoil before rainstorm tests | 24 |
| 17 | Close-up view of the semi-compacted fill treatment on St. Clair subsoil before rainstorm tests | 24 |
| 18 | Sediment load of runoff from the compacted fill treatment on the St. Clair subsoil | 26 |
| 19 | Close-up view of the tilled treatment on St. Clair subsoil 17 hours after the initial 63.5 mm (2.5 inch) artificial rainstorm | 27 |
| 20 | Plot view of the tilled treatment on St. Clair subsoil after 63.5 mm (2.5 inches) of artificial rain | 27 |
| 21 | Plot view of the tilled treatment on St. Clair subsoil after 127mm (5 inches) of artificial rain | 27 |
| 22 | Site area of Wymore subsoil during site preparation | 28 |
| 23 | Plot view of the tilled treatment on Wymore subsoil before application of artificial rain | 29 |
| 24 | Close-up view of the tilled treatment on Wymore subsoil before application of artificial rain | 29 |
| 25 | Plot view of the tilled treatment on Wymore subsoil immediately after 63.5mm (2.5 inches) of artificial rain | 31 |
| 26 | Plot view of the tilled treatment on Wymore subsoil 24 hours after the initial 63.5mm (2.5 inch) artificial rainstorm | 31 |

## FIGURES (continued)

No. Page

27 Close-up view of the tilled treatment on Wymore subsoil 24 hours after the initial 63.5mm (2.5 inch) artificial rainstorm 31

28 Plot view of the scalped treatment on Wymore subsoil before the rainstorm tests 32

29 Close-up view of the scalped treatment on Wymore subsoil before the rainstorm tests 32

30 Sediment load of runoff from the scalped treatment on the Wymore subsoil 33

31 Close-up view of the tilled treatment on Wymore subsoil one week after rainulator tests 34

32 Tilled treatment area on Pawnee subsoil during site preparation 35

33 Scalped treatment area on Pawnee subsoil during site preparation 35

34 Close-up view of the tilled treatment on Pawnee subsoil before rainstorm tests 37

35 Plot view of the tilled treatment on Pawnee subsoil before rainstorm tests 37

36 Close-up view of the tilled treatment on Pawnee subsoil after 18mm (0.71 inches) of artificial rain 37

37 Plot view of the tilled treatment on Pawnee subsoil after 63.5mm (2.5 inches) rainstorm 38

38 Plot view of the scalped treatment on Pawnee subsoil before rainstorm tests 38

39 Close-up view of the scalped treatment on Pawnee subsoil before rainstorm tests 36

## FIGURES (Continued)

| No. | | Page |
|---|---|---|
| 40 | Plot view of the scalped treatment on Pawnee subsoil 17 hours after 63.5 mm (2.5 inches) of artificial rain | 38 |
| 41 | Close-up view of the tilled treatment on Pawnee subsoil about 2 weeks after rainulator tests | 39 |
| 42 | Tilled treatment area on Mayberry subsoil during site preparation | 40 |
| 43 | Scalped treatment area on Mayberry subsoil during site preparation time | 40 |
| 44 | Scalped treatment area on Mayberry subsoil after 8 weeks of natural weathering | 40 |
| 45 | Plot view of the scalped treatment on Mayberry subsoil before rainstorm tests | 41 |
| 46 | Close-up view of the scalped treatment on Mayberry subsoil before rainstorm tests | 41 |
| 47 | Aggregate-size distribution for aggregates on Wymore and Mayberry subsoil before rainstorm tests | 42 |
| 48 | Sediment load of runoff from the scalped treatment on the Mayberry subsoil | 44 |
| 49 | Plot view of the tilled treatment on Mayberry subsoil before rainstorm tests | 45 |
| 50 | Close-up view of the tilled treatment on Mayberry subsoil before rainstorm tests | 45 |
| 51 | Plot view of the tilled treatment on Mayberry subsoil after 188mm (7.4 inches) of rain | 46 |
| 52 | Close-up view of the tilled treatment on Mayberry subsoil after 188mm (7.4 inches) of rain | 46 |

## FIGURES (continued)

| No. | | Page |
|---|---|---|
| 53 | Plot view of the scalped treatment on Mayberry subsoil after 188mm (7.4 inches) of rain | 47 |
| 54 | Close-up view of the scalped treatment on Mayberry subsoil after 188mm (7.4 inches) of rain | 47 |
| 55 | Nomograph for estimating the erodibility factor, K, of high clay subsoils | 75 |

# TABLES

| No. | | Page |
|---|---|---|
| 1 | Summary of Dates of Site Preparation and Rainulator Test | 9 |
| 2 | Observed Soil Loss and Infiltration on Subsoils During Successive Rainstorms | 10 |
| 3 | Observed Soil Loss and Infiltration on Nebraska Surface Soils During Successive Rainstorms | 15 |
| 4 | Observed and Predicted Soil Erodibility Factors for Tilled Subsoils | 49 |
| 5 | Observed and Predicted Soil Erodibility Factors for Scalped Subsoils | 50 |
| 6 | Observed and Predicted Soil Erodibility Factors for Surface Soils | 52 |
| 7 | Physical Characteristics of Soils Used in This Study | 58 |
| 8 | Chemical Composition of Soils Used in This Study | 60 |
| 9 | Clay Mineralogical Composition of Soils Used in This Study (percent of the clay fraction) | 62 |
| 10 | Estimates of Parameters in the Simple Linear Regression Equation of Kobs with Analyzed Soils Variables | 66 |
| 11 | Estimates of Partial Regression Coefficients in the Multiple Linear Regression Equation of Kobs with Soil Variables | 68 |
| 12 | Estimates of Partial Regression Coefficients in the Multiple Linear Regression Equation of Kobs with Surface Soil Variables | 70 |
| 13 | Estimates of Partial Regression Coefficients in the Weighted Multiple Linear Regression Equation of Kobs with Surface and Subsoil Variables | 72 |

## TABLES (continued)

No. Page

14 Estimates of Partial Regression Coefficients in the Multiple Linear Regression Equation of Kobs with Subsoil Variables 73

15 Comparison of the Soil Erodibility Factor, K, Determined in Field Experiments and Those Computed from the Subsoil Nomograph 78

16 Correlation Matrix of Surface Soil Variables (coefficient of correlation - r) 106

17 Correlation Matrix of Subsoil Variables (coefficient of correlation - r) 109

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# I. CONCLUSIONS

The nomograph developed by Wischmeier et al. (1971) to estimate erodibility factor, K, of surface soils could not be statistically improved upon even considering the large number of chemical and mineralogical parameters investigated as a part of this study.

The nomograph developed by Wischmeier et al. (1971) to predict the soil erodibility factor, K, of surface soils does not adequately predict the erodibility factor of high clay subsoils.

The number of observations on subsoils was too small to develop a universally applicable model for predicting subsoil erodibility. However, the observations made as a part of this study did allow the development of a nomograph which can be used to predict the erodibility factor, K, of high clay subsoils with very slow permeability and blocky or massive structure containing amorphous iron and aluminum hydrous oxides.

The average soil losses and infiltration rates were similar on the scalped and semi-compacted fill treatments on subsoils.

The scalped subsoil surface was chosen as the standard soil surface condition to be used for determining soil erodibility factors on subsoils.

A soil-management factor was introduced to describe the scalped subsoil treatment. This factor should replace the cropping-management factor in the Universal Soil-Loss Equation when used to predict subsoil erosion.

# II. RECOMMENDATIONS

The soil erodibility prediction nomograph developed for high clay subsoils is restricted in that it can be used only on subsoils with massive or blocky structure and very slow permeability. Since Wischmeier et al. (1971) has shown structure and permeability to be important factors in soil erodibility prediction of surface soils, it is highly probable that these factors are important in subsoils. It is recommended that more soil erodibility measurements be made on subsoils having structures other than massive or blocky and permeabilities other than very slow.

An important term in the proposed model to predict high clay subsoil erodibility is the amount of citrate-dithionite extractable iron and aluminum. The iron and aluminum removed by this reagent from the subsoils investigated in this study is thought to have existed in the subsoils as amorphous hydrous oxides. The amorphous hydrous oxides of iron and aluminum can serve as binding agents in soils, thereby, increasing aggregate stability, but the crystalline forms of iron and aluminum hydrous oxides do not affect aggregate stability. Since the citrate-dithionite reagent can extract both crystalline and amorphous hydrous oxides or iron, it is recommended that a procedure be developed which will distinguish between crystalline and amorphous forms of iron and aluminum hydrous oxides in soils.

Field observation indicated that initial moisture content of the subsoil could affect erodibility determinations. Additional work in this area is recommended.

Fulfillment of the above recommendations would allow a more universal application of a subsoil erodibility model such as developed in this study.

# III. INTRODUCTION

Sediment is a major pollutant of surface water in the United States. Much of the sediment is derived from agricultural land. However, with the extensive and rapid conversion of agricultural land to other uses such as housing, road, school, business, and industry, an increasing amount of sediment currently has its source in urban areas. Sediment yield from areas in intensive suburban developments is often appreciable larger than that of cultivated land in rural areas. Thus, techniques are needed for minimizing soil losses in urban situations, where soil erosion has received little attention in the past.

Sediment yield from agricultural land has been successfully described by the Universal Soil Loss Equation, which combines the principal factors that influence surface soil erosion by water. The equation takes the form:

$$A = RKLSCP$$

where

A is the soil loss expressed in the units selected for K and for the time period covered by factor R, short tons/acre.

R is the rainfall factor, usually expressed in units of rainfall-erosivity index, EI, ft-short tons/acre times the maximum 30-min intensity in inches/hour time $10^{-2}$.

K is the soil-erodibility factor, commonly expressed in short tons per acre per EI unit.

L is a slope-length factor, dimensionless ratio.

S is the slope-steepness factor, dimensionless ratio.

C is the cropping and management factor, dimensionless ratio.

P is the erosion control practice factor, dimensionless ratio.

The above equation can be expressed in metric units by multiplying the English EI units by 1.735 to arrive at the storm energy in tm/ha times the maximum 30-minute intensity in cm/hr. The factor for direct conversion of K to t/ha per metric EI unit is 1.292 (Wischmeier, 1972).

The most difficult parameter to be specified in the equation is the soil erodibility factor. Although the Universal Soil Loss Equation has been used successfully by the Soil Conservation Service for predicting soil losses and conservation measures on agricultural land, little attempt has been made to adapt the equation for use with urban construction site soil loss. A primary difficulty in using the Universal Soil Loss Equation for predicting soil erosion on construction areas is the evaluation of the erodibilities of subsoils, which are commonly heavier in texture than the surface soils for which existing relations have been derived. In addition, subsoils likely have aggregating agents that are very much different than those found in surface soils and the degree of soil aggregation is known to have a profound influence on soil erosion by water.

To allow accurate prediction of soil losses from urban construction sites, an improved method of relating the soil erodibility to basic soil parameters must be developed. The first step for such an improvement was made with the development of a nomograph from which soil erodibilities of predominant light-textured soils can be determined (Wischmeier et al. 1971). Soil parameters used in predicting the soil erodibility for surface soils are silt content, sand content, organic matter content, structure and permeability of the soil profile. Since the actual cohesion between soil particles is determined by chemical and mineralogical constituents, any effort to improve the existing procedure for predicting erodibilities of surface soils and develop a technique for estimating the erodibility of subsoils will likely utilize basic chemical and physical parameters.

The objectives of this study were: (1) to test the soil erodibility model on soils having textural extremes, which are commonly found in subsoils at construction sites but were not present in the surface soils from which the model was developed; (2) to determine various chemical, physical, and mineralogical characteristics of selected surface and subsoils and to relate these parameters to the erodibility factor, K; and (3) to attempt to improve the soil erodibility factor model so that subsoils are included, or to develop a separate model for use with subsoils, by utilization of data produced during accomplishment of the first two objectives.

Objective 1 was accomplished by determining the erodibility of six subsoils from the Midwestern part of the country by use of a field rainfall simulator. Subsoils were selected with variation in texture, iron oxide, and organic matter content. The observed erodibilities of subsoils were compared with the erodibility predicted by the erodibility nomograph to judge the accuracy of the nomograph for subsoils. Objective 2 was accomplished by determining a variety of chemical, mineralogical, and physical parameters of surface and subsoils for which the erodibilities had been measured. The erodibilities of the soils were than related statistically to the other parameters measured to determine those important in influencing intrinsic soil erodibility.

Objective 3 was met by multiple regression analyses of the data collected under Objectives 1 and 2 to produce models which successfully predict erodibility of surface and subsoils as functions of their chemical, mineralogical and physical properties. From the model for subsoil erodibility a nomograph was constructed which allows estimation of the erodibility factor, K, for high clay subsoils.

After the erodibility factor, K, has been determined, the Universal Soil Loss Equation may be used to predict soil loss from subsoils for a given rainfall pattern, slope steepness, and slope length. Once the potential soil loss from a site is established, soil erosion control measures may be recommended which are effective in maintaining soil loss from the area within established tolerances.

# IV. FIELD EXPERIMENTS

The soil-erodibility factor, K, in the Universal Soil Loss Equation (A = RKLSCP) is defined as the rate of soil erosion per unit of erosion-index (EI) from unit plots on that soil. An unit plot is defined as being 22.1 m (72.6 ft) long with a uniform length-wise slope of 9 percent in continuous fallow, tilled up and down the slope (Wischmeier and Smith, 1965). A further refinement of this definition is given by specifying that continuous fallow represents a condition in which land is tilled and kept free of vegetation for a period of two years or until prior crop residues have decomposed. Before conducting soil-loss measurements, the plot is plowed and placed in conventional corn seedbed each spring and is tilled as needed to prevent vegetal growth or crusting. Under these conditions, the factors L, S, C, and P in the universal soil loss equation each have a value of 1 and the soil erodibility factor, K, equals A/R, where A is the measured soil loss, while R represents the erosion-index or the rainfall factor (Wischmeier and Smith, 1965).

From the definition of the soil erodibility factor it may be inferred that determinations of K are most readily performed on surface soils. More recently, a soil erodibility nomograph was developed by Wischmeier et al. (1971) which permits predictions of the soil erodibility factor from routine laboratory determinations on soil and standard soil profile descriptions. The accuracy and validity of the nomograph was confirmed for 13 benchmark surface soils by comparing the predicted K values with those measured in long term, natural-rain plot studies. Actually, the nomograph's derivation was based on soil-loss measurements of mostly medium textured surface soils, causing some uncertainty as to its accuracy for high clay subsoils. To establish a greater accuracy in predictions of subsoil erodibility, soil losses were measured on selected sites of high clay subsoils using established simulated rainfall procedures. Two surface conditions, commonly found at subsoil sites, were evaluated. The erodibility factor of the subsoils for each of these treatments was computed by standard procedures. The accuracy of the nomograph was then checked for these soils by comparing measured and predicted values. Then, a selection was made as to which soil treatment should represent the standard surface conditions for soil erodibility determinations on subsoils.

## PROCEDURE

The subsoils selected were located in a wide geographical area in the middle West. The selections, primarily based on the clay content, were:

McGary silty clay near Bloomington, Monroe Co., Indiana
Portageville clay near Portageville, New Madrid Co., Missouri
St. Clair silty clay near Woodburn, Allen Co., Indiana
Wymore silty clay near Burr, Otoe Co., Nebraska
Pawnee clay loam near Burr, Otoe Co., Nebraska
Mayberry clay loam near Burr, Otoe Co., Nebraska

The soil profile descriptions of the above soils are given in Appendix A.

The erodibility factors, K, were measured and calculated for the surface soils on the Nebraska sites. These K values will be used in the statistical analysis phase of this project.

The general site areas were selected in cooperation with University (Purdue University and the University of Missouri) and Soil Conservation Service personnel using high clay content of the subsoil as the principal criterion. The clay contents of these subsoils, as determined by procedures outlined in Chapter V, are: McGary 39.8%, Portageville 66.5%, St. Clair 38.7%, Wymore 38.5%, Pawnee 35.4%, and Mayberry 33.9%. The specific locations were largely determined by practical considerations such as accessibility, proximity to a water source, cooperation of landowners and tenants, and natural topography.

Site preparation was in accordance with the procedures outlined in the Project Plan of the Research Proposal. The overburden soil was removed with a bulldozer, and the site area was sloped to 9 percent steepness. Three treatments were conducted on the McGary, Portageville, and St. Clair sites: scalped, tilled and semi-compacted fill. A third of the area that was sloped to 9 percent steepness with a bulldozer was used without farther manipulations for the scalped treatment. The tilled treatment consisted of plowing and disking to approximately 127mm (5 inches) another area similar to that used for the scalped treatment. The tilled treatment on the McGary, Portageville, and St. Clair subsoils received two thorough diskings (2-3 passes each time), one immediately following plowing, the other just before rain tests. The Nebraska sites received three thorough diskings, the third one performed about two weeks after site preparation. The semi-compacted fill treatment consisted of excavating the soil from another area of the sloped site to a depth of approximately 300 mm (12 inches), returning the removed soil back to the plot area and compacting the soil with the bulldozer tread. Only the scalped and tilled treatments were tested on the Nebraska sites. The deletion of the semi-compacted fill treatment from the Nebraska sites, which were prepared under the supplemental part of the project, was suggested by the similarity in results of soil loss and runoff observed earlier on the McGary and Portageville sites. Site preparation and rainfall test dates are summarized in Table 1.

Artificial rainstorms of about 63.5 mm (2.5 in) per hour were applied to replicated treatments on 1.8 by 10.7 m (6 by 35 ft) plots, using the rainfall simulator (rainulator) described by Meyer and McCune (1958). Each rainulator test series consisted of an initial run of 60 minutes followed 24 hours later by two 30-minute runs on the wet soil. On the Nebraska sites, the two 30-minute runs were combined in a single 60-minute storm. However, the data were divided into two 30-minute storms by using basic information such as sediment load and runoff data from this storm and an analytical procedure for generating hydrographs described by Foster et al. (1968). Runoff from each plot was collected by gutters which extended across the lower plot end and emptied into

Table 1. SUMMARY OF DATES OF SITE PREPARATION AND RAINULATOR TEST

| Soil[a] | Site Preparation | Rainulator Tests |
|---|---|---|
| McGary | 16 August 1971 | 16-17 September 1971 |
| Portageville | 1 September 1971 | 15-16 October 1971 |
| St. Clair | 10 June 1972 | 5-6 September 1972 |
| Wymore S | 28 June 1972 | 14-15 August 1972 |
| Pawnee S | 28 June 1972 | 16-17 August 1972 |
| Mayberry S | 28 June 1972 | 24-25 August 1972 |
| Wymore T | 28 June 1972 | 22-23 August 1972 |
| Pawnee T | 28 June 1972 | 14-15 August 1972 |
| Mayberry T | 28 June 1972 | 25-26 August 1972 |

[a] S = subsoil, T = topsoil

the approach of a 18.3 cm (0.6 ft), calibrated, HS-flume. The flume has a stilling well and stage recorder to measure the rate and amount of runoff (Meyer, 1960). Approximately one percent of the runoff was collected by a sampling slot located on an electrically powered rotating wheel placed in the runoff stream between the gutter and flume. When large soil particles (aggregates) were transported, 100 percent runoff samples were collected to insure that none of the large aggregates were missed because of non-passage through the sampling slot. Runoff samples were taken at 3-5 minute intervals during the runoff period. Soil loss and runoff were computed by integrating the measured hydrograph and acquired sediment content values of collected runoff samples. Computations were performed on the Purdue University CDC 6500 computer.

## RESULTS

The observed soil losses and infiltration rates for the subsoils tested are summarized in Table 2. Due to larger infiltration rates and/or

Table 2. OBSERVED SOIL LOSS AND INFILTRATION OF SUBSOILS DURING SUCCESSIVE RAINSTORMS

| Soil | Treatment | Storm duration min | Soil loss, t/ha(short tons/acre) | | | Slope, % | Infiltration mm(in) | Adjusted soil loss, t/ha (short tons/a)[a] |
|---|---|---|---|---|---|---|---|---|
| | | | Plot 1 | Plot 2 | Ave. | | | |
| McGary | Scalped | 60 | 24.91[b]<br>(11.11)[b] | 38.11<br>(17.00) | 38.11<br>(17.00) | 9.0 | 17.02<br>(0.67) | 54.88<br>(24.48) |
| | | 30 | 12.35<br>(5.51) | 13.61<br>(6.07) | 12.98<br>(5.79) | | 4.32<br>(0.17) | 18.70<br>(8.34) |
| | | 30 | 13.72<br>(6.12) | 16.03<br>(7.15) | 14.88<br>(6.64) | | 1.78<br>(0.07) | 21.43<br>(9.56) |
| | Semi-compacted fill | 60 | 33.33<br>(14.87) | 30.04<br>(13.40) | 31.69<br>(14.14) | 9.0 | 22.10<br>(0.87) | 45.64<br>(20.36) |
| | | 30 | 12.71<br>(5.67) | 16.10<br>(7.18) | 14.41<br>(6.43) | | 4.57<br>(0.18) | 20.74<br>(9.25) |
| | | 30 | 17.60<br>(7.85) | 15.87<br>(7.08) | 16.74<br>(7.47) | | 2.03<br>(0.08) | 24.10<br>(10.75) |
| | Tilled | 60 | 15.11<br>(6.74) | 14.39<br>(6.42) | 14.75<br>(6.58) | 9.0 | 27.43<br>(1.08) | 21.25<br>(9.48) |
| | | 30 | 11.25<br>(5.02) | 9.68<br>(4.32) | 10.47<br>(4.67) | | 4.06<br>(0.16) | 15.09<br>(6.73) |
| | | 30 | 11.66<br>(5.20) | 10.54<br>(4.70) | 11.10<br>(4.95) | | 2.29<br>(0.09) | 15.98<br>(7.13) |
| Portageville | Scalped | 60 | 3.38<br>(1.51) | 4.64<br>(2.07) | 4.01<br>(1.79) | 9.0 | 16.26<br>(0.64) | 5.78<br>(2.58) |
| | | 30 | 1.37<br>(0.61) | 4.17<br>(1.86) | 2.77<br>(1.24) | | 5.08<br>(0.20) | 3.99<br>(1.78) |
| | | 30 | 1.21<br>(0.54) | 3.18<br>(1.42) | 2.20<br>(0.98) | | 2.54<br>(0.10) | 3.16<br>(1.41) |
| | Semi-compacted fill | 60 | 3.27<br>(1.46) | 6.10<br>(2.72) | 4.69<br>(2.09) | 9.0 | 13.21<br>(0.52) | 6.75<br>(3.01) |
| | | 30 | 2.13<br>(0.95) | 2.51<br>(1.12) | 2.32<br>(1.03) | | 4.32<br>(0.17) | 3.34<br>(1.49) |
| | | 30 | 1.84<br>(0.82) | 3.47<br>(1.55) | 2.66<br>(1.19) | | 1.52<br>(0.06) | 3.83<br>(1.71) |
| | Tilled | 60 | 0.47<br>(0.21) | 0.96<br>(0.43) | 0.72<br>(0.32) | 9.0 | 32.26<br>(1.27) | 1.03<br>(0.46) |
| | | 30 | 0.90<br>(0.40) | 0.13<br>(0.06) | 0.52<br>(0.23) | | 16.26<br>(0.64) | 0.74<br>(0.33) |
| | | 30 | 0.61<br>(0.27) | 0.16<br>(0.07) | 0.38<br>(0.17) | | 8.13<br>(0.32) | 0.54<br>(0.24) |

Table 2 (continued). OBSERVED SOIL LOSS AND INFILTRATION OF SUBSOILS DURING SUCCESSIVE RAINSTORMS

| Soil | Treatment | Storm duration min | Soil loss, t/ha(short) tons/acre) Plot 1 | Plot 2 | Ave. | Slope, % | Infiltration mm(in) | Adjusted soil loss, t/ha (short tons/a)[a] |
|---|---|---|---|---|---|---|---|---|
| St. Clair | Scalped | 60 | 52.37<br>(23.36) | 44.58<br>(19.89) | 48.48<br>(21.63) | 9.0 | 8.89<br>(0.35) | 69.83<br>(31.15) |
| | | 30 | 23.47<br>(10.47) | 19.77<br>(8.82) | 21.63<br>(9.65) | | 1.78<br>(0.07) | 31.14<br>(13.89) |
| | | 30 | 20.98<br>(9.36) | 16.43<br>(7.33) | 18.61<br>(8.30) | | 0.76<br>(0.03) | 26.95<br>(12.02) |
| | Semi-compacted fill | 60 | 46.25<br>(20.63) | 42.03<br>(18.75) | 44.14<br>(19.69) | 9.0 | 10.16<br>(0.40) | 63.57<br>(28.36) |
| | | 30 | 16.79<br>(7.49) | 16.41<br>(7.32) | 16.60<br>(7.41) | | 3.56<br>(0.14) | 23.90<br>(10.66) |
| | | 30 | 12.71<br>(5.67) | 14.32<br>(6.39) | 13.52<br>(6.03) | | 1.78<br>(0.07) | 19.45<br>(8.68) |
| | Tilled | 60 | 31.52<br>(14.06) | 31.56<br>(14.08) | 31.54<br>(14.07) | 9.0 | 21.84<br>(0.86) | 45.42<br>(20.26) |
| | | 30 | 14.68<br>(6.55) | 9.66<br>(4.31) | 12.17<br>(5.43) | | 6.35<br>(0.25) | 17.53<br>(7.82) |
| | | 30 | 14.57<br>(6.50) | 10.81<br>(4.82) | 12.69<br>(5.66) | | 3.81<br>(0.15) | 18.27<br>(8.15) |
| Wymore | Scalped | 60 | 45.95<br>(20.50) | 49.21<br>(21.95) | 47.58<br>(21.23) | 8.7 | 20.57<br>(0.81) | 71.60<br>(31.94) |
| | | 30 | 22.28<br>(9.94) | 20.80<br>(9.28) | 21.54<br>(9.61) | | 7.37<br>(0.29) | 32.30<br>(14.41) |
| | | 30 | 16.88<br>(7.53) | 13.98<br>(6.24) | 15.43<br>(6.89) | | 4.83<br>(0.19) | 23.09<br>(10.30) |
| | Tilled | 60 | 0.00<br>(0.00) | 0.00<br>(0.00) | 0.00<br>(0.00) | 9.1 | 63.50<br>(2.50) | 0.00<br>(0.00) |
| | | 30 | 4.75<br>(2.12) | 3.38<br>(1.51) | 4.07<br>(1.82) | | 25.40<br>(1.00) | 5.85<br>(2.61) |
| | | 30 | 7.20<br>(3.21) | 7.15<br>(3.19) | 7.17<br>(3.20) | | 20.32<br>(0.80) | 10.24<br>(4.57) |

Table 2 (continued). OBSERVED SOIL LOSS AND INFILTRATION OF SUBSOILS DURING SUCCESSIVE RAINSTORMS

| Soil | Treatment | Storm duration min | Soil loss, t/ha(short tons/acre) | | | Slope, % | Infiltration mm (in) | Adjusted soil loss, t/ha (short tons/a)[a] |
|---|---|---|---|---|---|---|---|---|
| | | | Plot 1 | Plot 2 | Ave. | | | |
| Pawnee | Scalped | 60 | 47.39<br>(21.14) | 38.24<br>(17.06) | 42.82<br>(19.10) | 8.9 | 19.56<br>(0.77) | 63.26<br>(28.22) |
| | | 30 | 23.38<br>(10.43) | 16.78<br>(7.48) | 20.08<br>(8.96) | | 5.59<br>(0.22) | 29.68<br>(13.24) |
| | | 30 | 27.01<br>(12.05) | 17.17<br>(7.66) | 22.09<br>(9.86) | | 2.54<br>(0.10) | 32.66<br>(14.57) |
| | Tilled | 60 | 11.21<br>(5.00) | 27.98<br>(12.48) | 19.59<br>(8.74) | 8.9 | 43.69<br>(1.72) | 28.83<br>(12.86) |
| | | 30 | 16.03<br>(7.15) | 15.40<br>(6.87) | 15.71<br>(7.01) | | 7.11<br>(0.28) | 23.20<br>(10.35) |
| | | 30 | 15.56<br>(6.94) | 18.88<br>(8.42) | 17.22<br>(7.68) | | 5.33<br>(0.21) | 25.40<br>(11.33) |
| Mayberry | Scalped | 60 | 70.68<br>(31.53) | 66.15<br>(29.51) | 68.42<br>(30.52) | 9.0 | 10.67<br>(0.42) | 98.70<br>(44.03) |
| | | 30 | 30.82<br>(13.75) | c | 30.82<br>(13.75) | | 1.27<br>(0.05) | 43.00<br>(19.18) |
| | | 30 | 23.45<br>(10.46) | c | 23.45<br>(10.46) | | 0.00<br>(0.00) | 32.71<br>(14.59) |
| | Tilled | 60 | 4.77<br>(2.13) | 2.31<br>(1.03) | 3.54<br>(1.58) | 9.1 | 44.96<br>(1.77) | 5.10<br>(2.24) |
| | | 30 | 2.35<br>(1.05) | c | 2.35<br>(1.05) | | 15.24<br>(0.60) | 3.45<br>(1.54) |
| | | 30 | 3.52<br>(1.57) | c | 3.52<br>(1.57) | | 10.16<br>(0.40) | 5.16<br>(2.30) |

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[a] Soil loss values were adjusted for slope steepness and slope length to unit plots (Wischmeier and Smith, 1965).

[b] This value was deleted in subsequent computations due to reduced soil loss resulting from a severe concavity at the plot end. At the end of the 60-minute storm, sedimentation had eliminated the irregularity in slope.

[c] These values could not be determined because a natural rainstorm, which occurred after the 60-minute storm, destroyed the plot.

storage capacities and reduced runoff velocities, soil losses from the tilled treatment were consistently smaller than those from the scalped treatment. The combined soil losses from the two 30-minute storms on the scalped plots were, for all but the Portageville subsoil, less than the soil losses from the 60-minute initial storm. This tendency may be explained by the mass removal of loose soil material as was evident by the larger soil content in runoff samples collected during the first storm in comparison to those collected during the 30-minute storms. On the other hand, the tilled treatment for all soils showed larger soil losses for the combined 30-minute storms than for the 60-minute storm. These latter findings reflect decreased infiltration rates and void storage as well as increased runoff velocities following slaking of clods during the course of the experiment.

Average soil losses and infiltration rates of the semi-compacted fill treatment of the McGary, Portageville, and St. Clair subsoils were generally similar to those for the scalped treatment during corresponding storms. Infiltration rates during corresponding storms tended to be slightly larger on the filled treatment than on the scalped treatment for the McGary and St. Clair soils; the reverse trend was observed for the Portageville soil. However, the observed differences between these two treatments are relatively small and are presumably within experimental error of determinations. Because of the similarity in data between the filled and scalped treatments, the semi-compacted fill treatment was deleted from further consideration on the Nebraska sites.

Appreciable differences in soil loss within a treatment were obtained between subsoils. The largest soil erosion rate was obtained on the scalped treatment of the Mayberry subsoil during the 60-minute storm, 98.7 t/ha (44.0 short tons/acre); this was followed by the Wymore, 71.6 t/ha (31.9 short tons/acre) and St. Clair, 69.8 t/ha (31.2 short tons/acre). Next in this sequence were Pawnee, 63.3 t/ha (28.2 short tons/acre), McGary, 54.9 t/ha (24.5 short tons/acre) and, a significant last, Portageville, 5.8 t/ha (2.6 short tons/acre). This same sequence also resulted if soil losses of the two 30-minute storms were added, except that the positions of Pawnee and Wymore were interchanged. The Pawnee subsoil showed a nearly constant soil erosion rate during successive rainstorms. A similar tendency was observed on the Portageville subsoil, whereas all other subsoils tested showed an appreciable decrease in soil erosion rates when progressing from storm 1 to storm 3. Some of the reasons for these differences will be discussed later.

The tilled treatment showed the opposite trend for soil erosion rates from that of the scalped treatment. On all subsoils except St. Clair, soil erosion rates during the two 30-minute storms were larger than those of the 60-minute storm. Soil loss from the second 30-minute storm was generally larger than that from the first 30-minute storm. No satisfactory explanation can be given for the deviant response of the St. Clair subsoil, except that a rapid breakdown of clods upon wetting, followed by sealing and a subsequent mass removal of small and readily transportable soil particles, led to initial high soil losses. The observed increase in soil erosion rates from the tilled treatment with successive storms can be attributed to a reduction in surface roughness and infiltration rates, leading to larger runoff velocities and ipso facto larger detachment and transport rates.

A summary of the observed soil losses and infiltration rates for the Nebraska surface soils is given in Table 3.

## FIELD OBSERVATIONS ON INDIVIDUAL SUBSOILS

### McGary subsoil

The McGary subsoil, a lake bed deposit, is a very heterogeneous soil. Appreciable variation (nearly linear) in clay content was evident from the upper to the lower end of the plots. Also, textural, chemical, and mineralogical variation could be visually discerned at any given location on the plots. The impact of these variations on soil loss is difficult to assess, but is thought to have increased soil erosion rates because of reduced structural homogeneity. A view of the plots

Table 3. OBSERVED SOIL LOSS AND INFILTRATION OF NEBRASKA SURFACE SOILS DURING SUCCESSIVE RAINSTORMS

| Soil | Treatment | Storm duration min | Soil loss, t/ha(short tons/acre) | | | Slope, % | Infiltration mm (in) | Adjusted soil loss, t/ha (short tons/a)[a] |
|---|---|---|---|---|---|---|---|---|
| | | | Plot 1 | Plot 2 | Ave. | | | |
| Wymore | Tilled | 60 | 11.03<br>(4.92) | 10.98<br>(4.90) | 11.01<br>(4.91) | 5.6 | 38.35<br>(1.51) | 30.31<br>(13.52) |
| | | 30 | 7.40<br>(3.30) | 7.89<br>(3.52) | 7.64<br>(3.41) | | 7.37<br>(0.29) | 21.05<br>(9.39) |
| | | 30 | 8.02<br>(3.58) | 7.29<br>(3.25) | 7.66<br>(3.42) | | 5.84<br>(0.23) | 21.07<br>(9.40) |
| Pawnee | Tilled | 60 | 18.09<br>(8.07) | 17.01<br>(7.59) | 17.55<br>(7.83) | 7.3 | 42.42<br>(1.67) | 33.74<br>(15.05) |
| | | 30 | 10.56<br>(4.71) | 11.66<br>(5.20) | 11.11<br>(4.96) | | 12.45<br>(0.49) | 21.32<br>(9.51) |
| | | 30 | 9.46<br>(4.22) | 11.46<br>(5.11) | 10.46<br>(4.67) | | 11.94<br>(0.47) | 20.06<br>(8.95) |
| Mayberry | Tilled | 60 | 18.34<br>(8.18) | 17.04<br>(7.60) | 17.69<br>(7.89) | 8.5 | 29.21<br>(1.15) | 27.66<br>(12.34) |
| | | 30 | 12.55<br>(5.60) | 9.73<br>(4.34) | 11.14<br>(4.97) | | 6.35<br>(0.25) | 17.40<br>(7.76) |
| | | 30 | 13.43<br>(5.99) | 10.20<br>(4.55) | 11.81<br>(5.27) | | 5.08<br>(0.20) | 18.45<br>(8.23) |

[a] Soil loss was adjusted for slope steepness and slope length to unit plots (Wischmeier and Smith, 1965).

of semi-compacted fill, scalped and tilled treatments is shown in Figures 1, 2 and 3, respectively, with close-ups of the soil surface for these treatments in Figure 4, 5, and 6.

Plot preparation on this site differed from those of other sites in that polyethylene sheets were used to cover the plot area between site preparation and tests. This may have affected the weathering process in two respects. Wetting by natural rainfall in the intervening period was prevented, thereby retarding the attainment of an adequately weathered surface condition on the filled and scalped treatment. Secondly, loose soil on the scalped plots was not removed by runoff from natural rainstorms before the commencement of rainulator tests. Hence, a larger than average amount of sediment may have resulted from the removal of loose soil material during the 60-minute storm. On the other hand, this effect was compensated, at least in part, by the absence of loose soil material produced during natural weathering processes.

To obtain uniform slopes on the scalped plots, a final reshaping of the surface with a 1-m wide improvised blade appeared necessary one day before the scheduled rainulator test. One plot, however, retained a severe concavity. Therefore, soil-loss values during the 60-minute storm from this plot were excluded from analysis.

The tilled treatment represented a condition with appreciable void storage. However, the surface clods broke down rapidly thereby filling up voids (Figure 7).

Rills on this subsoil did not appear to be an important source of soil in the first 127 mm (5 in) of artificial rain under the soil surface conditions prevailing at this site. Only the upper plot end of the tilled treatment showed the presence of some minor rills.

## Portageville clay

The study on Portageville clay differed in several respects from all other experiments:

1. The study was conducted in the fall.
2. Clods in the tilled treatment had a high moisture content at the time of the rainulator tests.
3. This subsoil had the highest clay percentage (66.5%) of all subsoils studied.
4. This subsoil had an unusually high organic carbon content, which is known to be an important parameter in the soil erodibility factor.

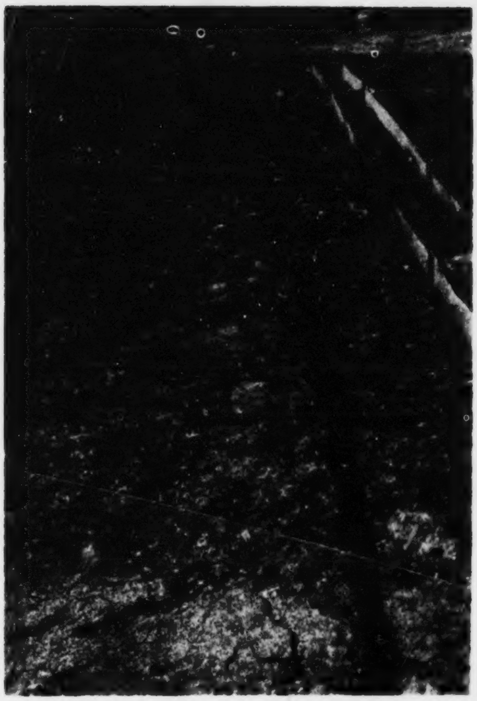
It is not clear which of these factors might have contributed the most to the relatively low rates of soil erosion.

The weathering period led to very similar soil conditions between the semi-compacted fill and scalped treatment. The plots had distinct rills, which occurred mostly in residual bulldozer tracks. The soil surface consisted of an agglomeration of aggregates, 56% of which were in the 4-7 mm (0.16-0.28 in) size fraction while most of the remaining aggregates were larger than 7 mm (0.28 in). The aggregates appeared to be quite stable due to a high moisture level. However, upon air drying and submersion in water under laboratory conditions the aggregates disintegrated in a matter of seconds. This suggests that soil erosion rates from these treatments might have been more severe if prolonged weathering, especially drying, had taken place before the rainulator tests. This drying would have to have been longer than 3 weeks since the last natural rain in the vicinity of this site occurred 3 weeks before the rainulator test.

Plot observations during and after rainstorms suggested that most soil in runoff originated from rills where sufficient concentration of flow enabled transport of large aggregates. The importance of this effect in soil erosion can be seen in Figure 8, where the rill portion in the photograph shows mostly coarse aggregates embedded or still attached to the soil mass, while the interrill region exhibits a much more uniform texture consisting of finer aggregates. Also, a 3- to 4-fold increase in measured soil content upon full sampling of runoff over that obtained by sampling 1% of runoff with the rotating wheel with sampling slot (Meyer, 1960) indicated the importance of soil erosion by aggregate detachment and transport.

The surface roughness of the interrill region on the scalped (Figure 8) and semi-compacted fill treatment indicated a large degree of stability of individual aggregates. Also, it appeared that aggregates resisted detachment and transport into existing rills by splash, which is considered to be an important mode of soil erosion from upland areas.

The tilled treatment yielded large clods, which were still very wet at the time of the rainulator tests. The stability of these clods after 127 mm (5 in) of artificial rain at 63.5 mm (2.5 in) per hour was not



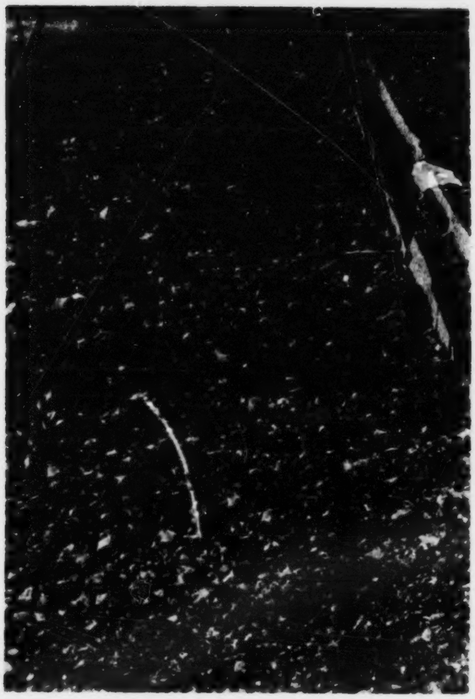
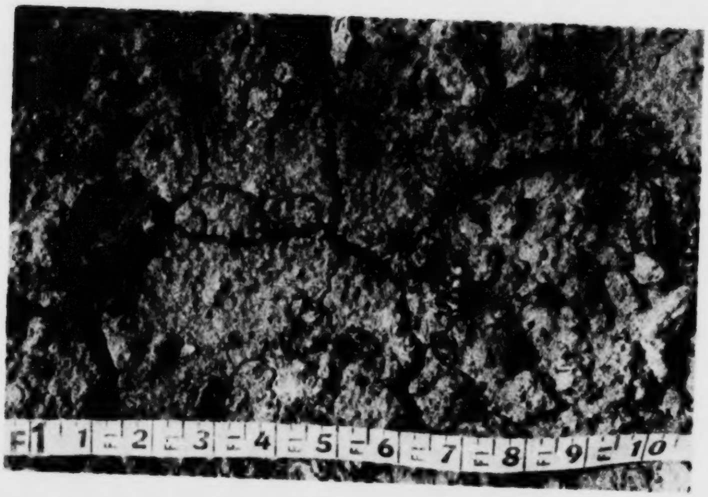


Figure 1. Plot view of the semi-compacted fill treatment on the McGary subsoil before rainstorm tests.

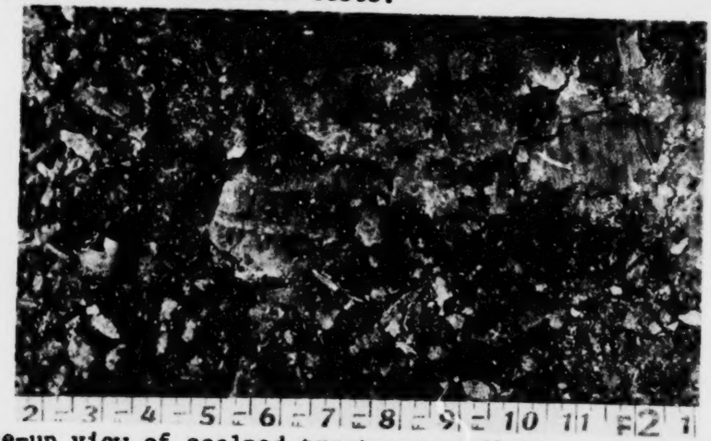
Figure 3. Plot view of the tilled treatment on the McGary subsoil before rainstorm tests.

Figure 2. Plot view of the scalped treatment on the McGary subsoil before rainstorm tests.



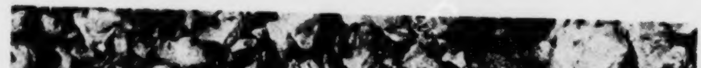
1 2 3 4 5 6 7 8 9 10

Figure 4. Close-up view of the semi-compacted fill treatment on McGary subsoil before rainstorm tests.



2 3 4 5 6 7 8 9 10 11 2 1

Figure 5. Close-up view of scalped treatment on McGary subsoil before rainstorm tests.



1 2 3 4 5 6 7 8 9 10

Figure 6. Close-up view of tilled treatment on the McGary subsoil before rainstorm tests.

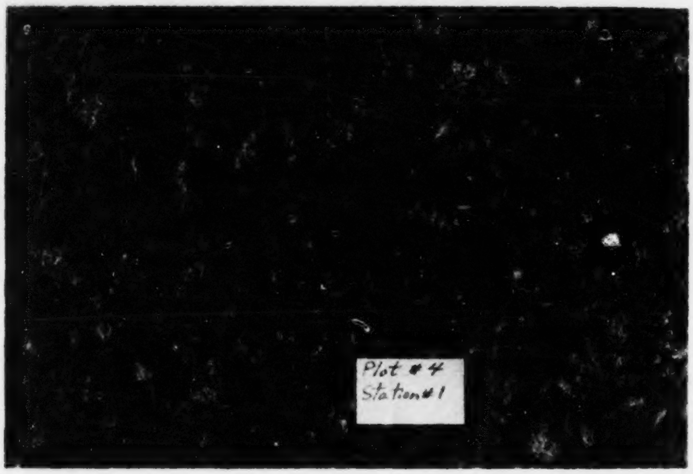


Figure 7. Surface condition of tilled treatment on McGary subsoil after 63.5 mm (2.5 inches) of artificial rain.

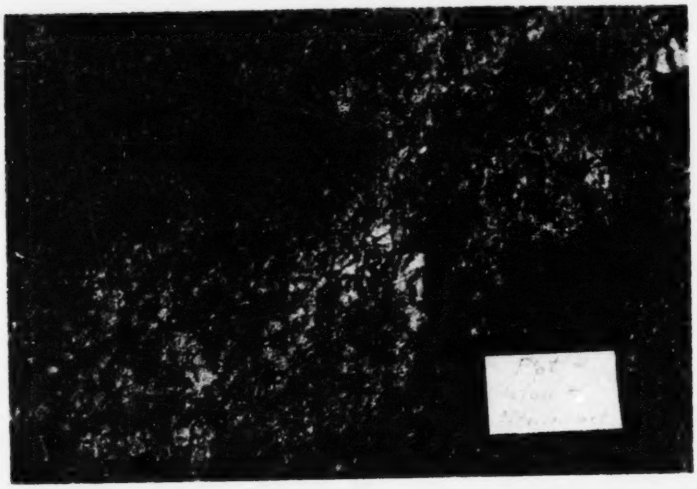


Figure 8. Close-up view of scalped treatment on Portageville subsoil after 127 mm (5 inches) of artificial rain.

appreciably affected (Figure 9) by impacting raindrops. Consequently, the large voids between clods stored sizable quantities of water, thereby reducing runoff. Also, the tortuous pathway of flow to the lower plot end reduced runoff velocities and, thus, soil detachment by shear flow. Although some disintegration of clods was visible after the rain tests (Figure 9) soil particles detached from clods were deposited in the void spaces between clods.

Figures 10 and 11 show the plot condition of the tilled and scalped treatment, respectively, after 127 mm (5 in) of artificial rain.

### St. Clair silty clay

Like the McGary subsoil, the St. Clair subsoil was a lake bed deposit of non-uniform composition. The non-uniformity in this subsoil resulted mainly from a cut into a 16% natural slope. As a consequence, the lower 3.0 m (10 ft) of the plot area consisted of soil material from the B-horizon. However, within a single horizon the subsoil appeared to be quite uniform in contasts to the McGary subsoil. A second difference was the presence of finer cracks in the St. Clair subsoil than in the McGary (Figures 15 and 17). These cracks may explain the lower infiltration rate during the 60-minute test on the St. Clair subsoil for both the scalped and semi-compacted fill treatments.

Figures 12, 13, and 14 show the surface condition of the scalped, tilled, and semi-compacted fill treatments, respectively, with close-ups of each treatment in Figures 15, 16, and 17. In contrast to the subsoil on the McGary site, the St. Clair subsoil was exposed to natural weathering for at least 10 weeks. In fact, this site was exposed longer to weathering than any other site in this project. Rills were in strong evidence at the time of rainulator tests on both the scalped and filled treatment. Rilling became more severe during the course of the experiments. The effect of weathering is apparent in Figure 18 showing a relatively high soil content in runoff samples during the initial portion of the 60-minute storm.

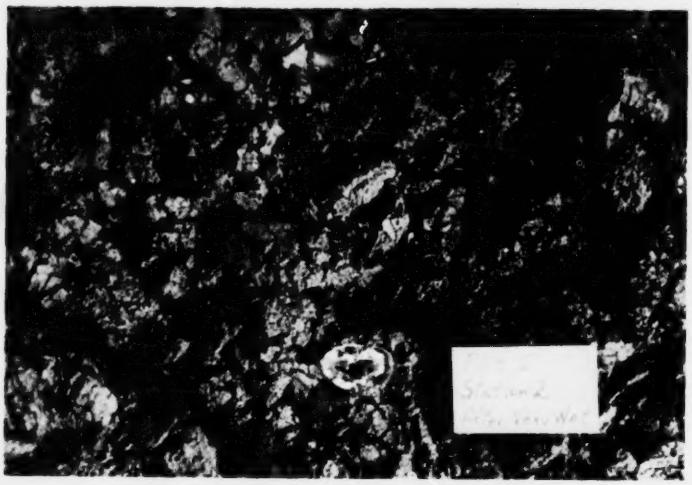


Figure 9. Close-up view of tilled treatment on Portageville subsoil after 127 mm (5 inches) of artificial rain.

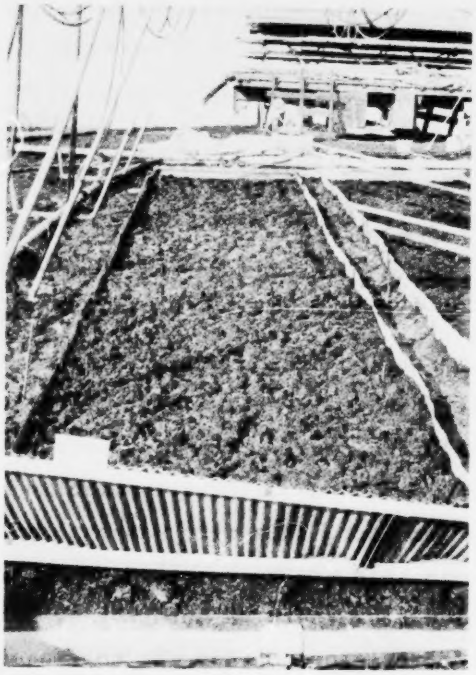


Figure 10. Plot view of tilled treatment on Portageville subsoil after 127mm (5.0 inches) of artificial rain.

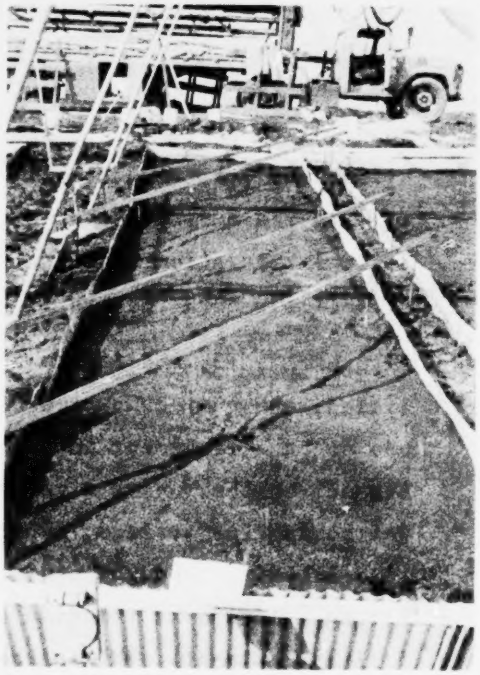


Figure 11. Plot view of scalped treatment on Portageville subsoil after 127mm (5.0 inches of artificial rain.

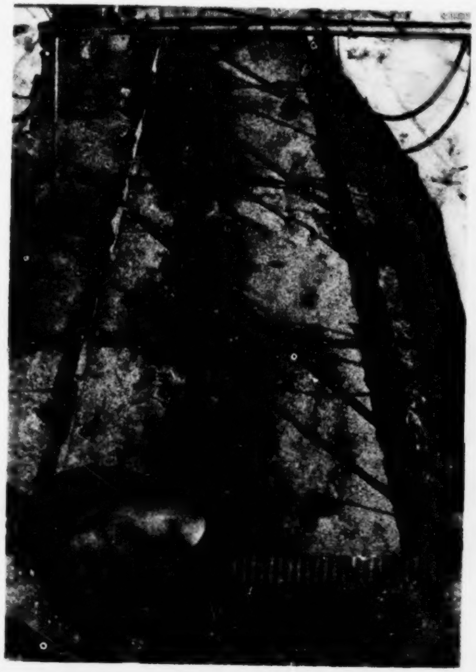


**Figure 12.** Plot view of scalped treatment on St. Clair subsoil before rainstorm tests.

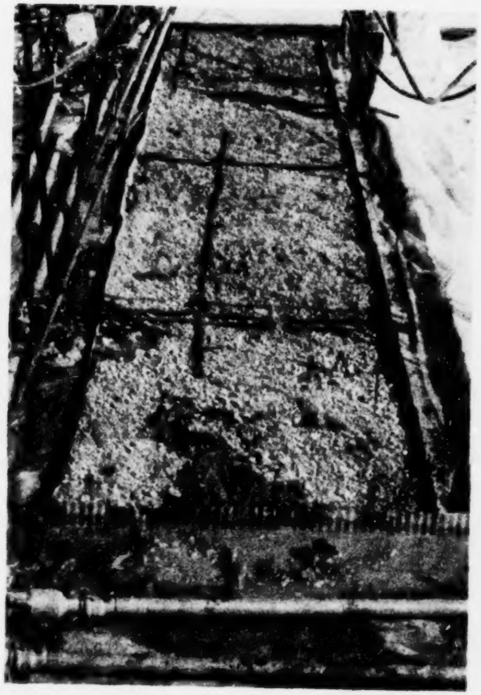


**Figure 13.** Plot view of tilled treatment on St. Clair subsoil before rainstorm tests.

**Figure 14.** Plot view of semi-compacted fill treatment on St. Clair subsoil before rainstorm tests.

Figure 15. Close-up view of the scalped treatment on St. Clair subsoil before rainstorm tests.

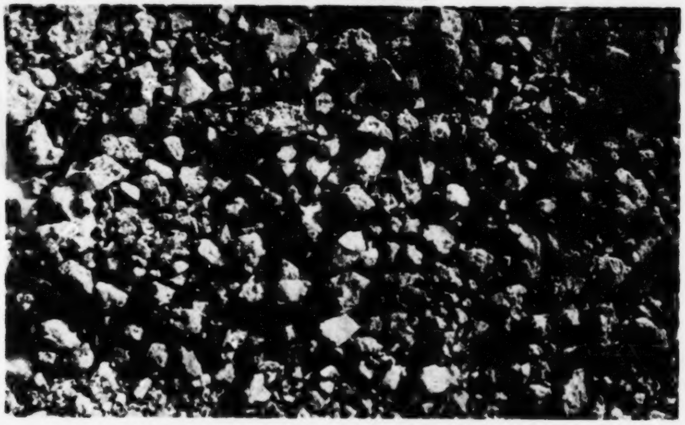


Figure 16. Close-up view of the tilled treatment on St. Clair subsoil before rainstorm tests.

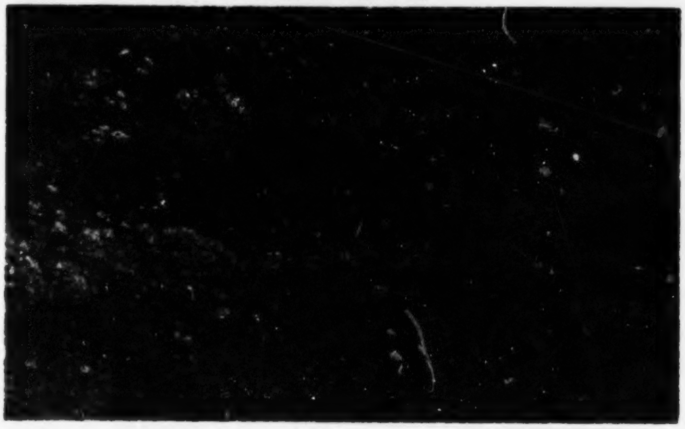


Figure 17. Close-up view of the semi-compacted fill treatment on St. Clair subsoil before rainstorm tests.

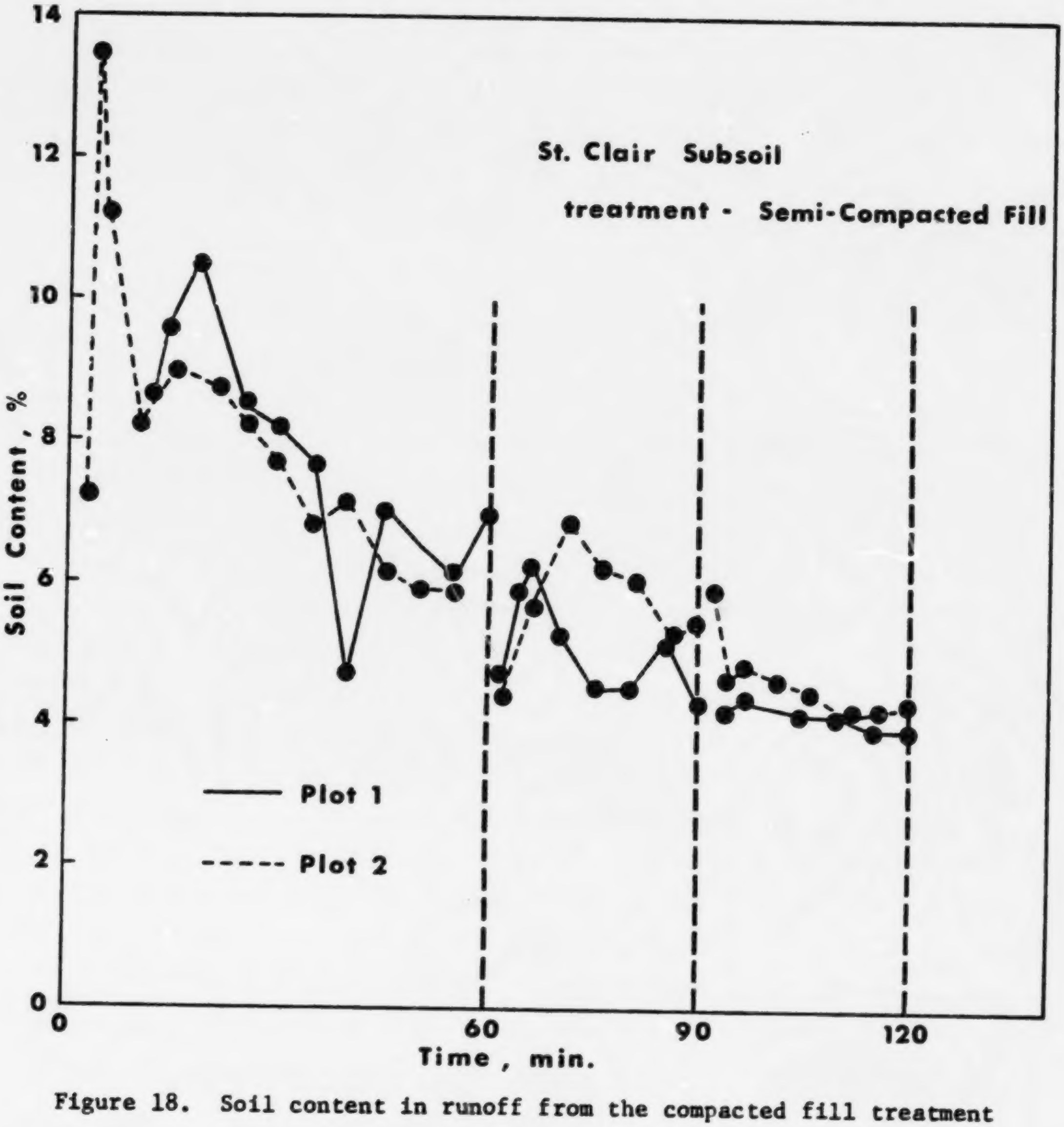


Figure 18. Soil content in runoff from the compacted fill treatment on the St. Clair subsoil.

The tilled treatment was disked immediately before the application of artificial rains. During the 60-minute storm, clods in this treatment slaked relatively fast thereby filling up voids (Figure 19). At 20-minutes into this storm, runoff from this treatment had reached appreciable levels. Rills were very apparent at the end of the 60-minute storm (Figure 20) and were mostly concentrated in the lower 3.0 m (10 ft) section of the plot area representing the B-horizon. Rills did not extend beyond 4.6 m (15 ft) from the plot end even after 63.5 mm (2.5 in) of additional rain (Figure 21). It should be noted that the tilled treatment on the St. Clair soil produced high soil losses during the first 60-minutes of rain.

### Wymore silty clay

Site preparation on the Wymore subsoil is shown in Figure 22. The Wymore subsoil was an extremely friable material which, after plowing followed by two diskings (Figure 22) and two weeks of natural weathering, readily broke into small aggregates during successive diskings. Figures 23 and 24 show the surface condition of the tilled treatment plot area after a final disking immediately before the application of artificial rain. The tilled treatment on this subsoil most nearly resembled the plot condition of surface soil studied for erodibility factor determinations. The tilled treatment produced a condition that was able to absorb almost all rain applied during the first rainstorm. Slaking of soil clods and aggregates was almost non-existent, though 60-minutes of rain did produce some soil consolidation. The soil surface retained a large degree of roughness due to stable aggregates adhering to the soil surface. The low runoff rate and "spongy" nature of this soil in the tilled treatment can be seen in Figure 25, taken at the end of the 60-minute storm. The stability of individual aggregates prevented effective sealing of the soil surface. Consequently, the tilled soil retained a high water absorptive capacity. Infiltration during the combined 30-minute storms was large on the tilled treatment plots and far exceeded infiltration observed on the scalped treatment plots during corresponding storms (Table 2). The surface

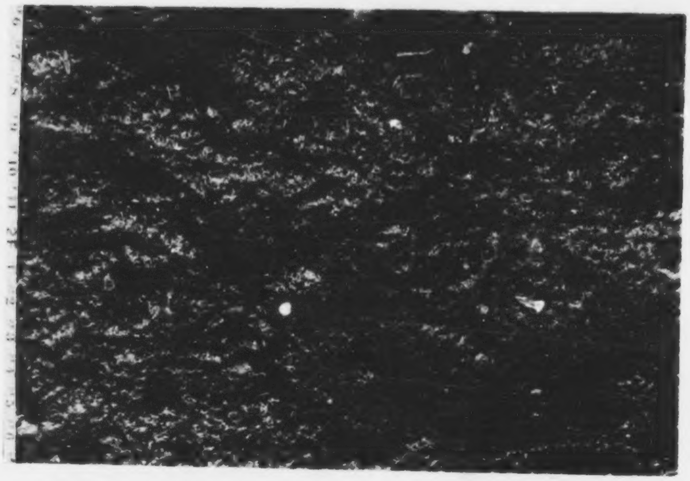


Figure 19. Close-up view of the tilled treatment on St. Clair subsoil 17 hours after the initial 63.5 mm (2.5 inch) artificial rainstorm.

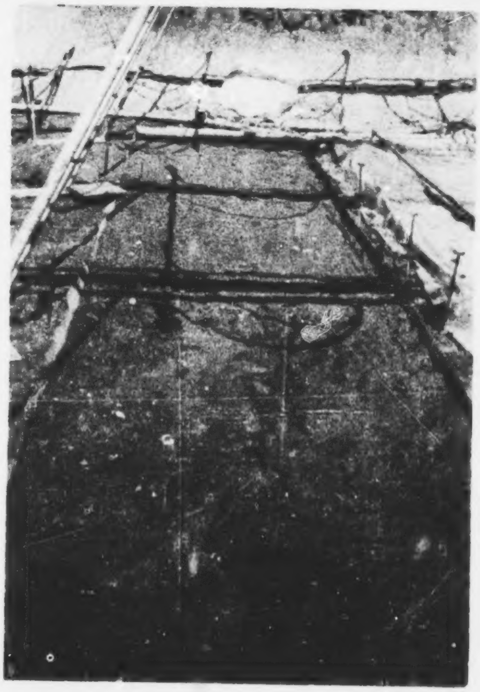


Figure 20. Plot view of the tilled treatment on St. Clair subsoil after 63.5 mm (2.5 inches) of artificial rain.

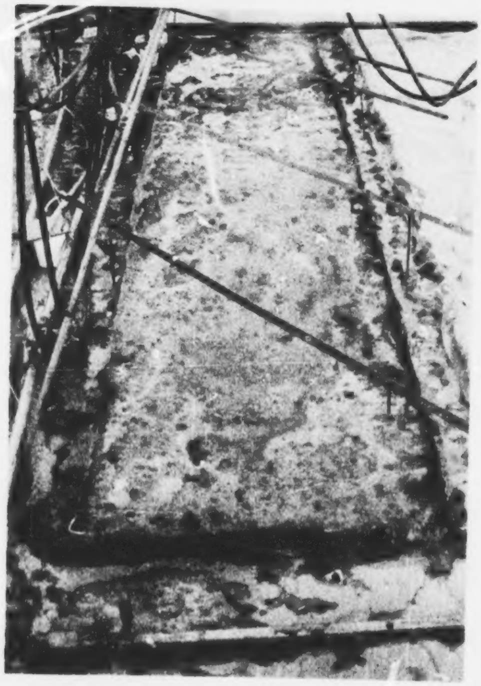


Figure 21. Plot view of the tilled treatment on St. Clair subsoil after 127mm (5 inches) of artificial rain.

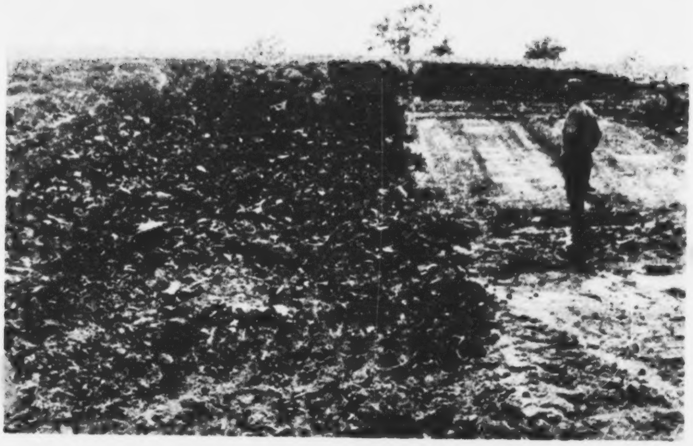


Figure 22. Site area of Wymore subsoil during site preparation.

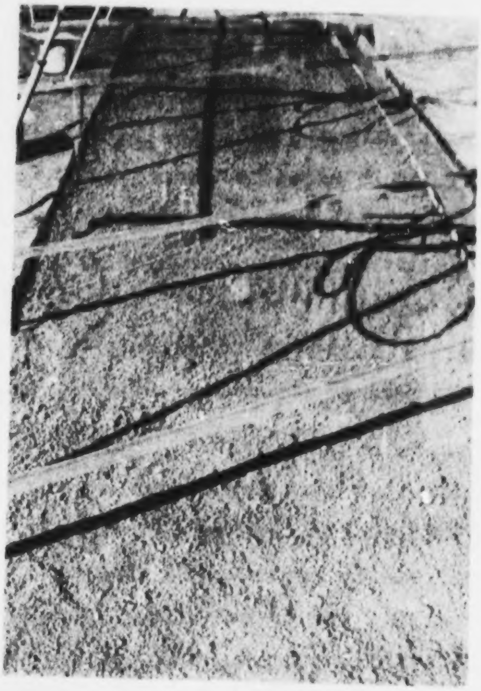


Figure 23. Plot view of the tilled treatment on Wymore subsoil before application of artificial rain.

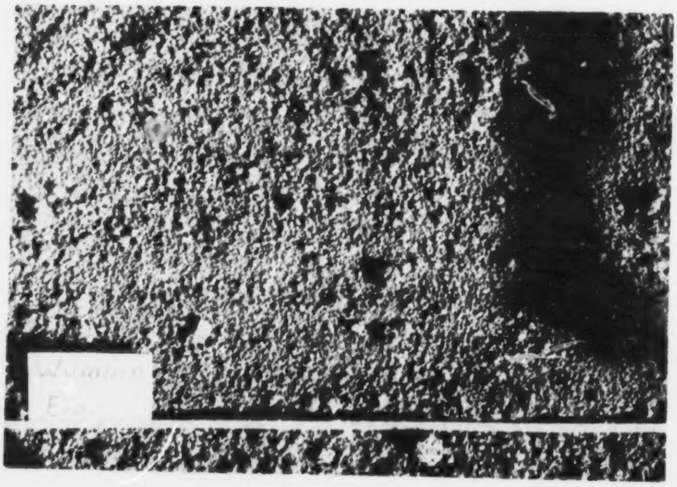


Figure 24. Close-up view of the tilled treatment on Wymore subsoil before application of artificial rain.

condition of the tilled soil after 24 hours of drying (Figures 26 and 27), however, was very similar to that of the scalped-treatment soils before rain tests (Figures 28 and 29). Apparently, the loose, yet stable, intergranular matrix produced by the tilled treatment provided ample storage for infiltrating water, while the weathered surface represented an agglomorate of aggregates which was similar to that produced by the scalped treatment. The reason for the stability of individual aggregates is not clear but is probably related to the chemical composition of the soil.

The scalped-treatment soil showed a hexagonal crack pattern with about 50 mm (2 in) diameter hexagons overlaid with numerous aggregates. These aggregates, of which 2/3 were in the 0.5-5 mm (0.02-0.20 in) size fraction, were readily detachable. Consequently, mass removal of aggregates in rills, fed by interrill sources through sheet flow and splash, led to initially large soil content in the runoff. As the application of rain continued, a gradual decrease in the soil content of runoff was observed (Figure 30). Rain applied during the first 12 to 15 minutes of the first storm was largely absorbed in soil cracks which subsequently were closed by the swelling soil.

Observations at this site suggest that following a rainstorm and subsequent drying, the original condition of a weathered surface is quickly re-established. Figure 31 shows the surface condition of this subsoil one week after the completion of rainulator tests.

### Pawnee clay loam

The preparational phase of the Pawnee site is shown in Figures 32 and 33 for the tilled and scalped treatments, respectively. The Pawnee subsoil was extremely difficult to till especially in a dry state. Plowing followed by three thorough diskings, each disking consisting of two to three passes, did not appreciably reduce clod sizes. The final clod size achieved before application of artificial rain varied from about 25 to 76 mm (1 to 3 in) (Figure 34). Figure 35 shows the tilled plot before the application of rain. A rain of less than 30-minutes was

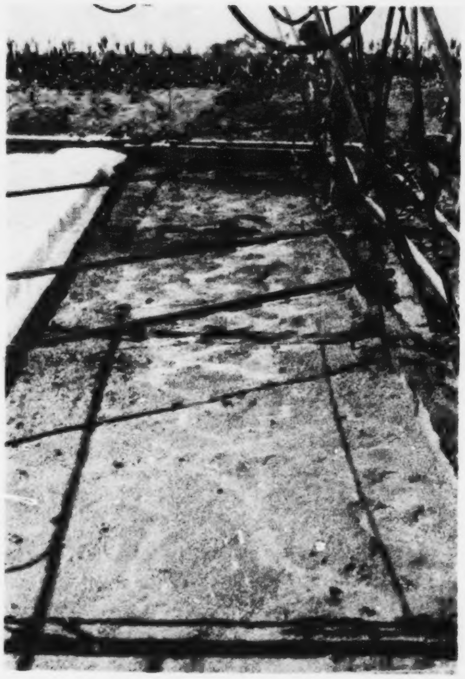


Figure 25. Plot view of the tilled treatment on Wymore subsoil immediately after 63.5 mm (2.5 inches) of artificial rain.

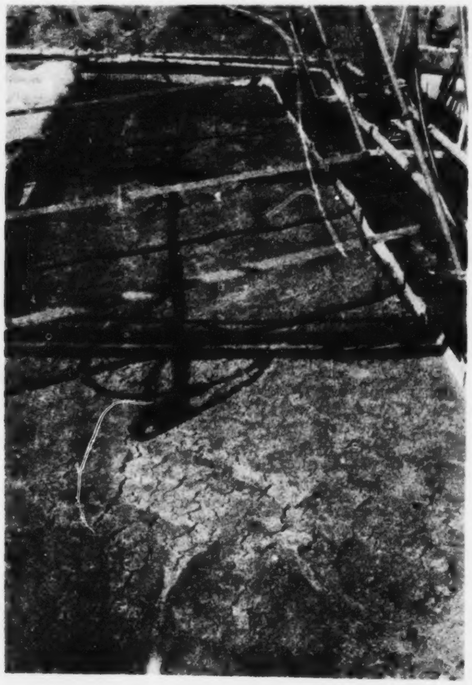


Figure 26. Plot view of the tilled treatment on Wymore subsoil 24 hours after the initial 63.5 mm (2.5 inches) of artificial rainstorm.

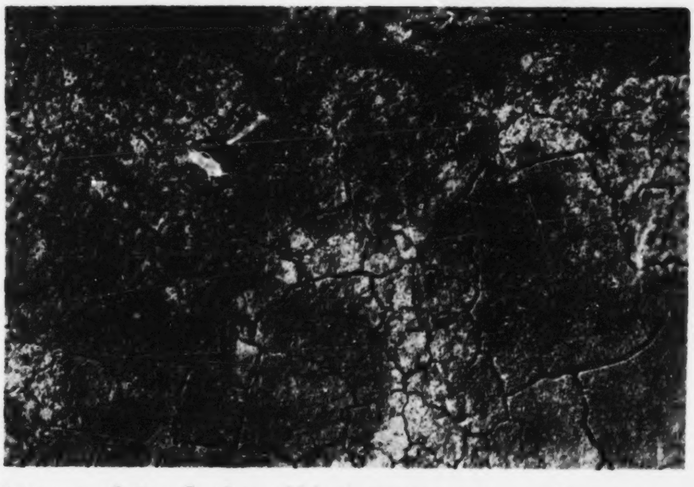


Figure 27. Close-up view of the tilled treatment on Wymore subsoil 24 hours after the initial 63.5 mm (2.5 inch) artificial rainstorm.

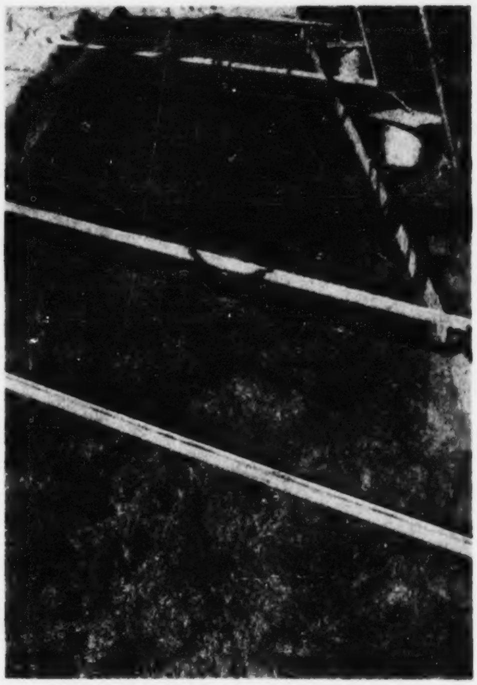


Figure 28. Plot view of the scalped treatment on Wymore subsoil before the rainstorm tests.

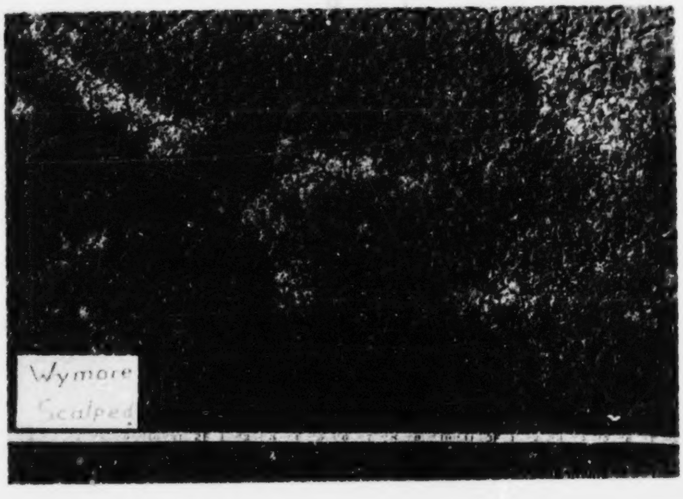


Figure 29. Close-up view of the scalped treatment on Wymore subsoil before the rainstorm tests.

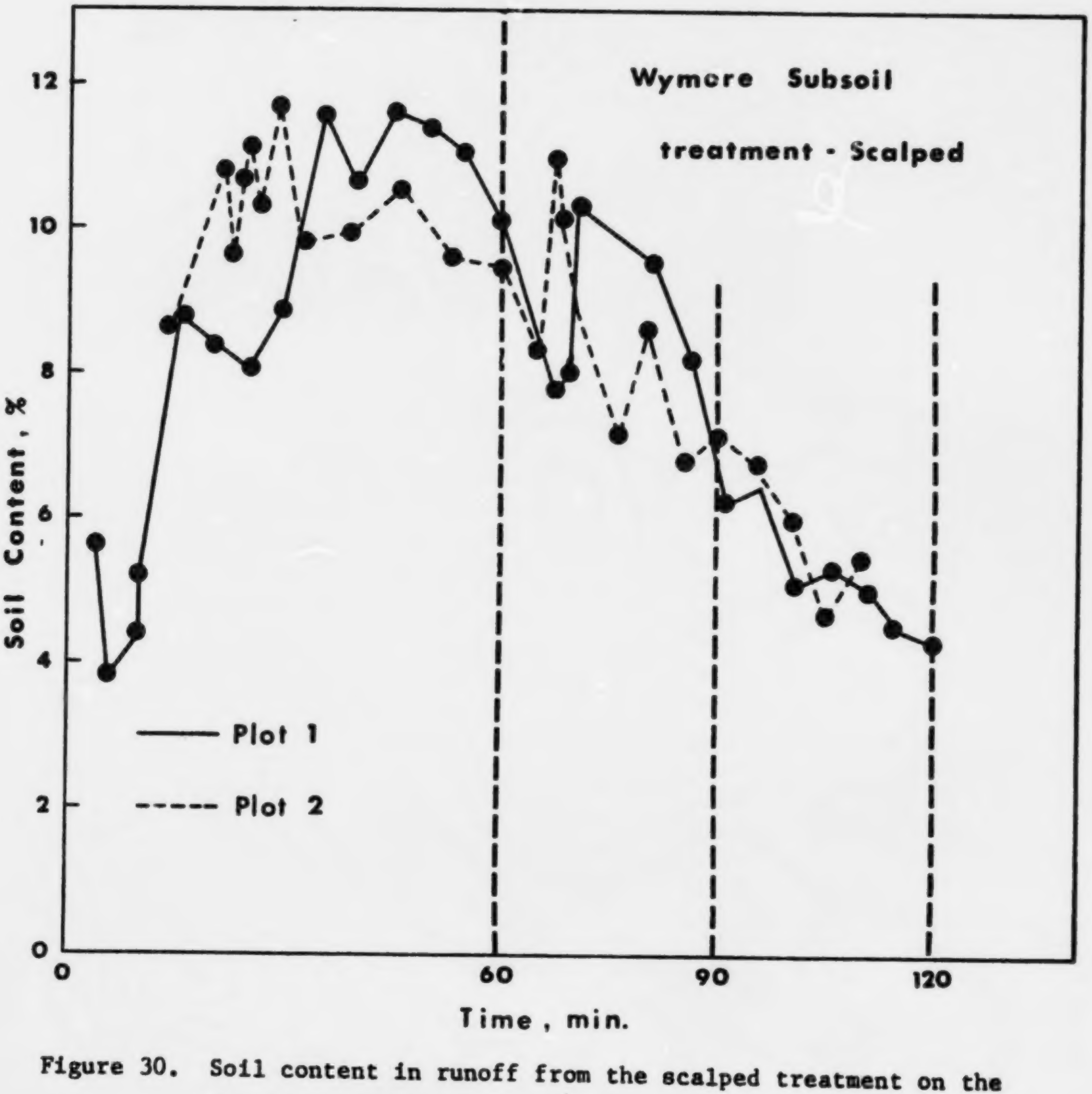


Figure 30. Soil content in runoff from the scalped treatment on the Wymore subsoil.

Figure 31. Close-up view of the tilled treatment on Wymore subsoil one week after rainulator tests.

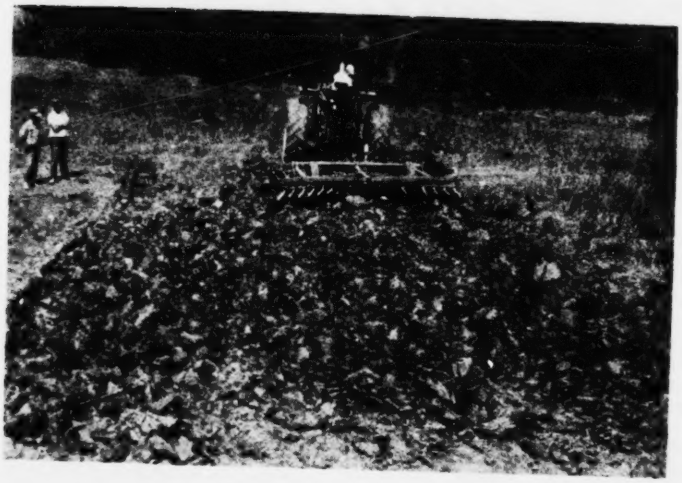


Figure 32. Tilled treatment area on Pawnee subsoil during site preparation.

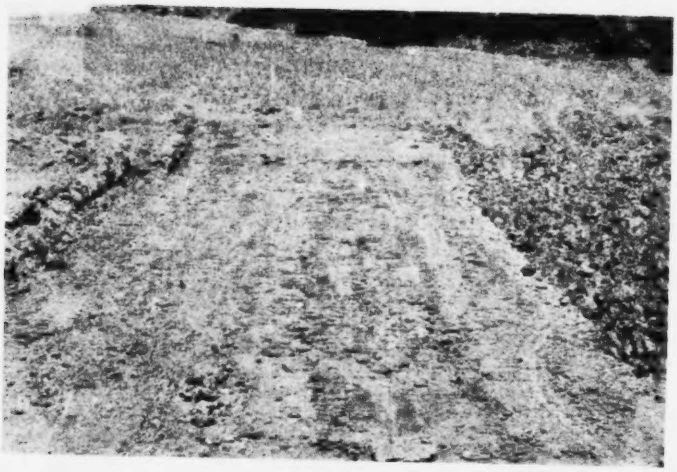


Figure 33. Scalped treatment area on Pawnee subsoil during site preparation.

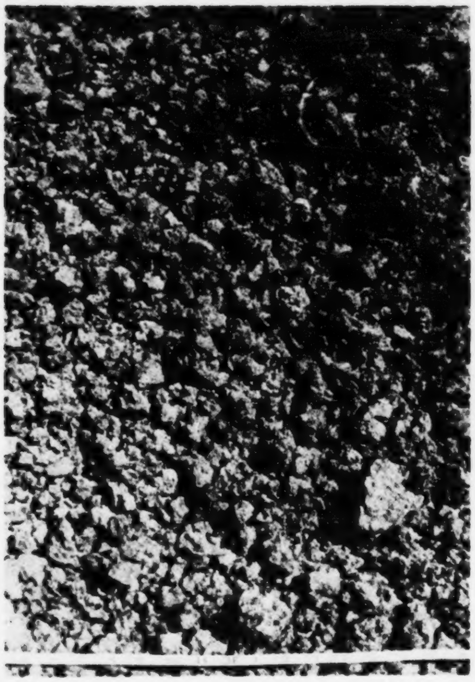


Figure 34. Close-up view of the tilled treatment on Pawnee subsoil before rainstorm tests.

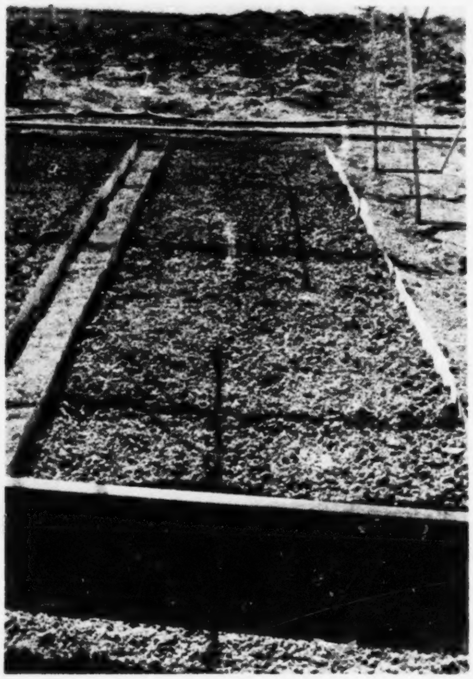


Figure 35. Plot view of the tilled treatment on Pawnee subsoil before rainstorm tests.

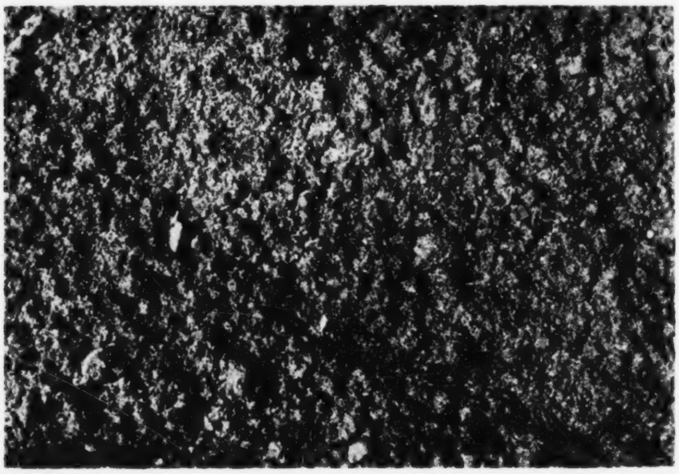


Figure 36. Close-up view of the tilled treatment on Pawnee subsoil after 18 mm (0.71 inches) of artificial rain.

needed to produce an effective surface seal caused by slaking of the clods. Figure 36 shows the surface condition of the tilled plot after 17 minutes of rain, while Figure 37 gives an overview of this plot following the 60-minute storm. Some rill development was evident at the end of the 60-minute storm.

The scalped treatment morphology prior to the rain tests is shown in Figures 38 and 39. Selective soil erosion on this subsoil is in strong evidence as demonstrated by the deposition of white colored silt and fine sand in the rills or depressions of the plot. The readily dispersable nature of this soil is not fully understood, but may be related, at least in part, to the relatively low levels of amorphous hydrous oxides of iron and aluminum. The uniformity in soil erosion rates for the 60-minute and 30-minute rainstorms on this treatment is probably related to the dispersable nature of this soil, although sediment content of runoff samples declined somewhat during the 30-minute storms. About 127 mm (5 in) of artificial rain and 61 mm (2.4 in) of natural rainfall eliminated any visible difference in surface condition between the scalped and tilled treatment. A plot view of the scalped treatment 24 hours after the 60-minute rainstorm is shown in Figure 40, while a close up view of the soil surface 2 weeks after all rainstorms is shown in Figure 41.

### Mayberry clay loam

The preparational phase on the Mayberry site is shown in Figures 42 and 43 for the tilled and scalped treatments, respectively. The two-month period between site preparation and rainulator tests yielded a highly weathered subsoil with numerous aggregates loosely bound to the soil surface (Figure 44). Figure 45 shows the surface condition of the scalped treatment before rainulator tests, while a close-up view is shown in Figure 46. The largest frequency of aggregates was in the 1 to 2 mm (0.04 to 0.08 in) size fraction (Figure 47). The maximum frequency in aggregate size on this soil was appreciably smaller than that for the Wymore subsoil. A possible explanation for the increase

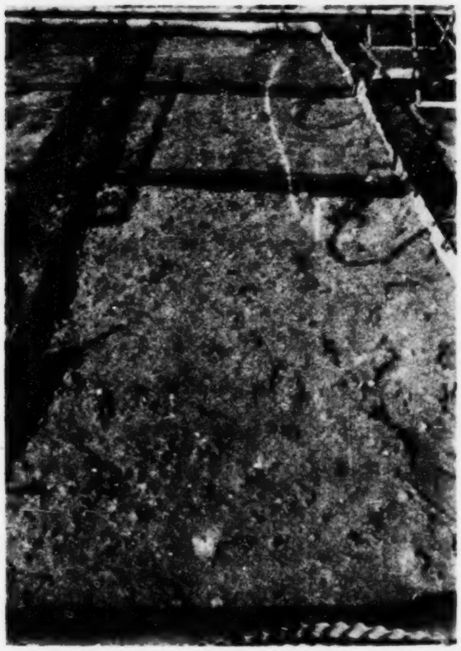


Figure 37. Plot view of the tilled treatment on Pawnee subsoil after 63.5 mm (2.5 inch) rainstorm.

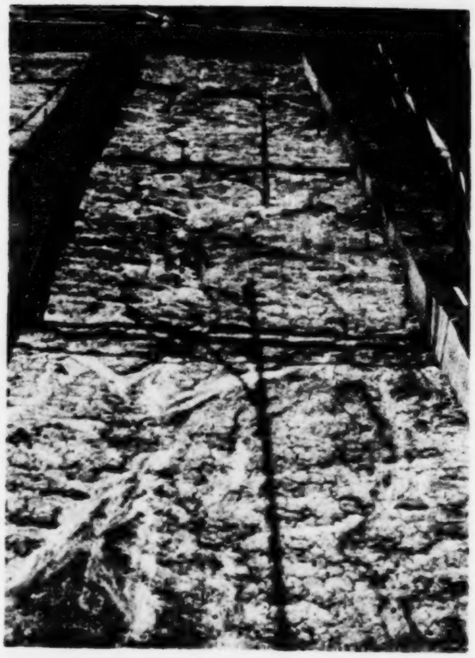


Figure 38. Plot view of the scalped treatment on Pawnee subsoil before rainstorm tests.

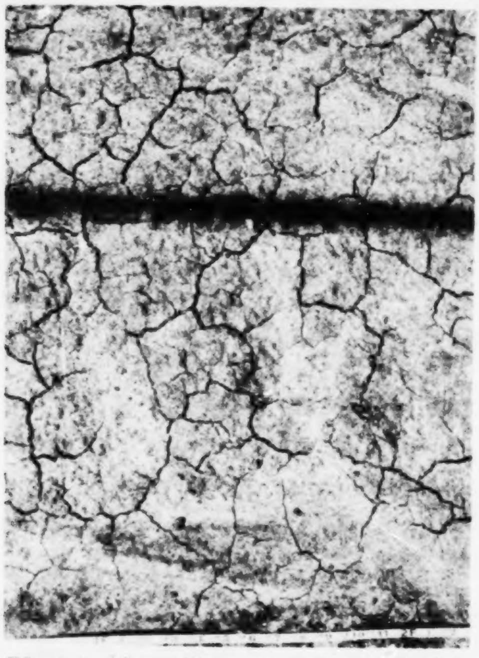


Figure 39. Close-up view of the scalped treatment on Pawnee subsoil before rainstorm tests.

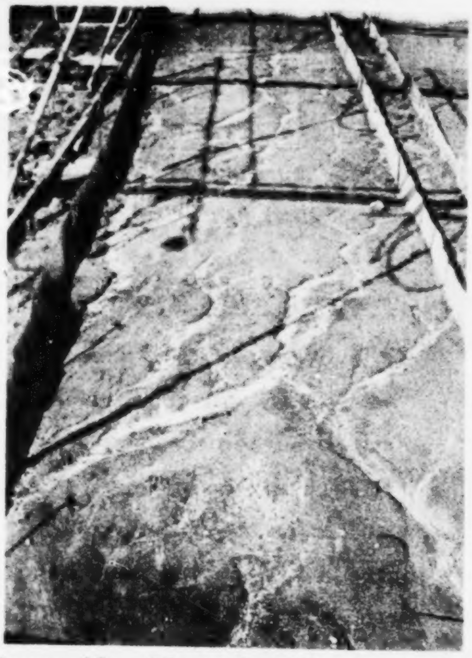


Figure 40. Plot view of the scalped treatment on Pawnee subsoil 17 hours after 63.5mm (2.5 inches) of artificial rain.

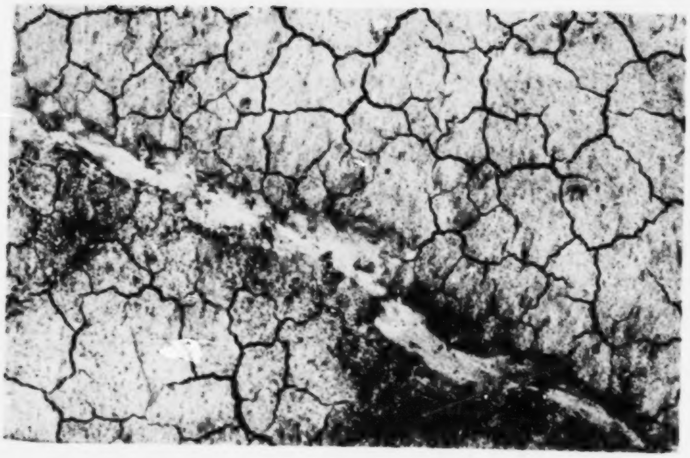


Figure 41. Close-up view of the tilled treatment on Pawnee subsoil about 2 weeks after rainulator tests.

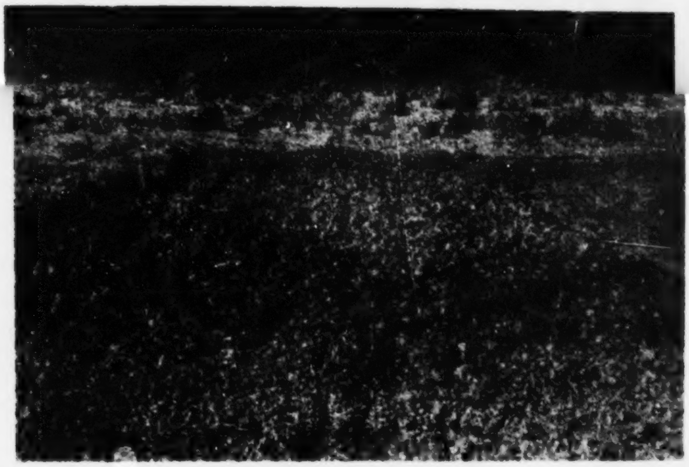


Figure 42. Tilled treatment area on Mayberry subsoil during site preparation.

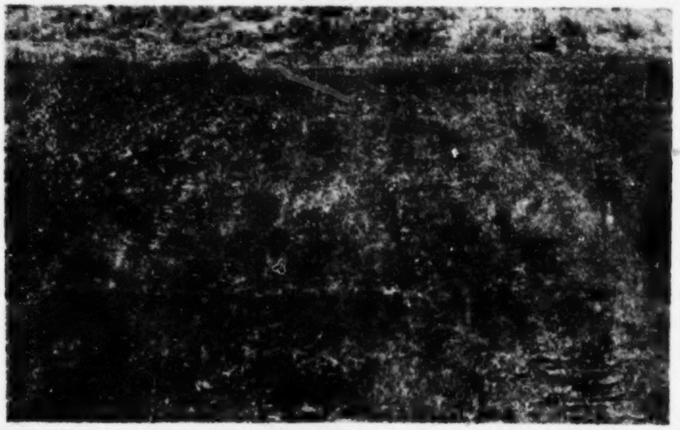


Figure 43. Scalped treatment area on Mayberry subsoil during site preparation time.

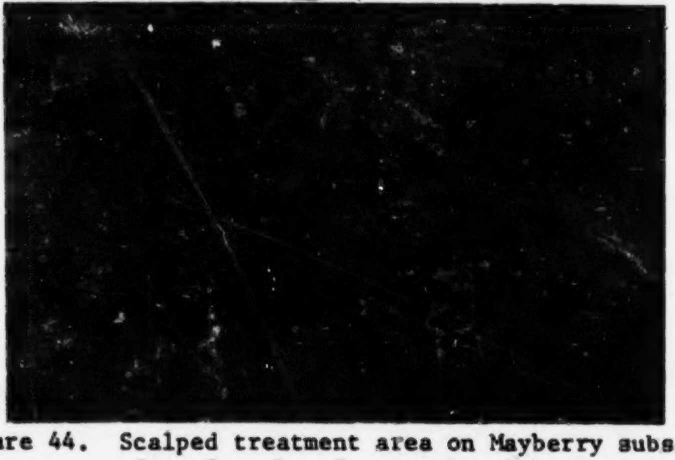


Figure 44. Scalped treatment area on Mayberry subsoil after 8 weeks of natural weathering.

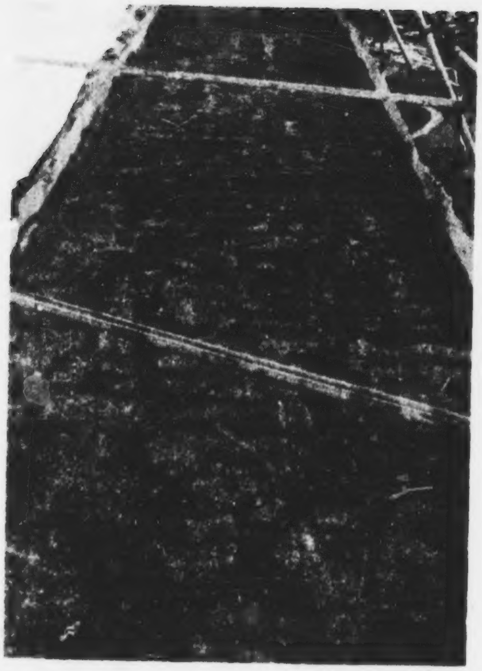


Figure 45. Plot view of the scalped treatment on Mayberry subsoil before rainstorm tests.

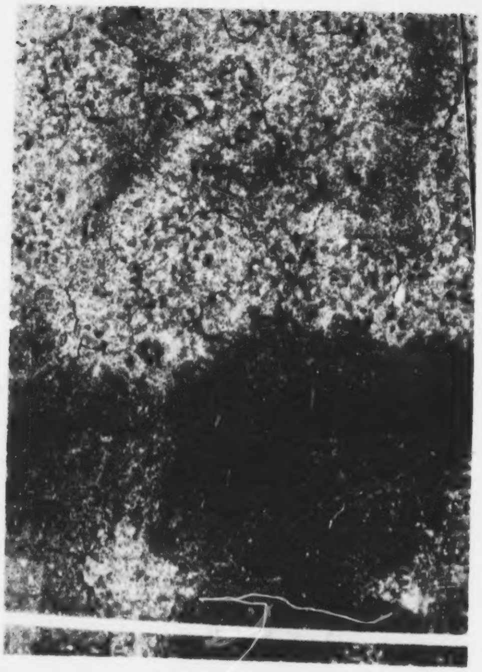


Figure 46. Close-up view of the scalped treatment on Mayberry subsoil before rainstorm tests.

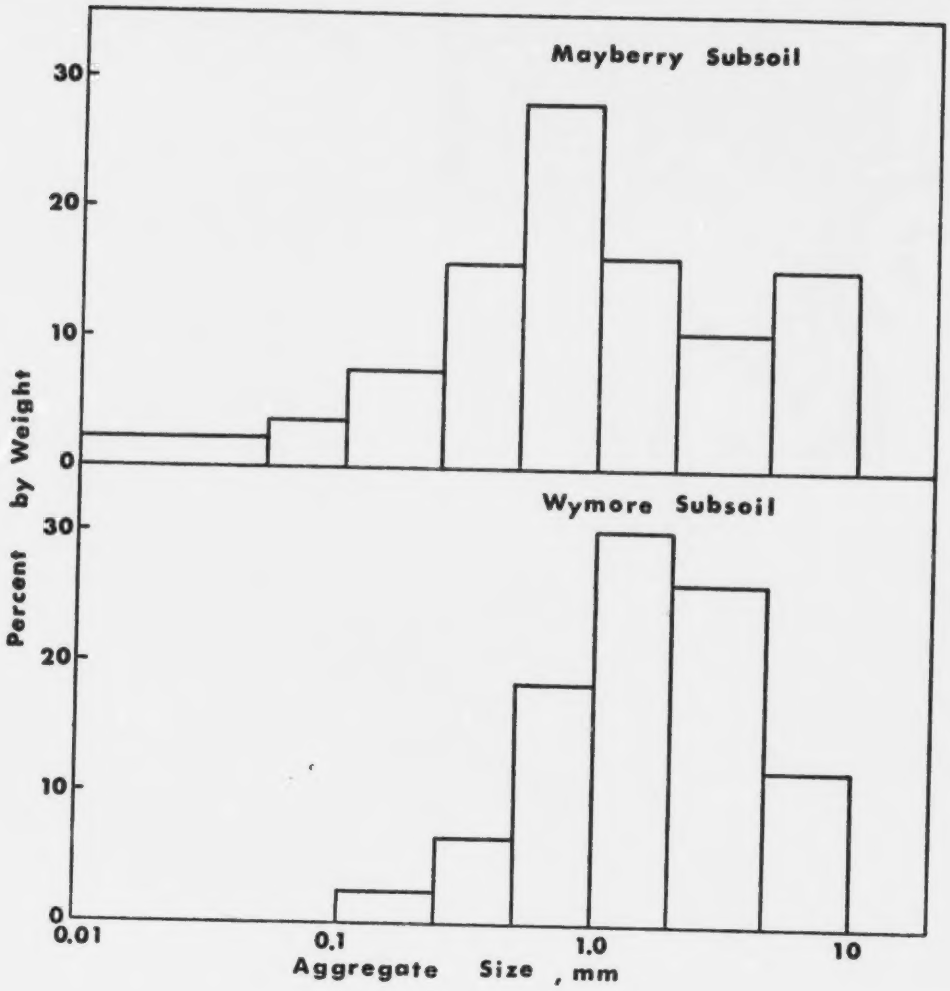


Figure 47. Aggregate-Size Distribution for Aggregates on Wymore and Mayberry Subsoil Before Rainstorm Tests

in soil loss from the Mayberry subsoil over that of the Wymore subsoil during the 60-minute storm (Table 2) may be the more readily detachable and transportable nature of aggregates in the Mayberry subsoil. Also, the soil content trend for runoff from the scalped treatment of the Wymore and Mayberry subsoils were very similar (Figures 30 and 48). It should be noted, however, that the data obtained from the Mayberry subsoil for the two 30-minute storms had to be synthesized because of the confounding influence of a natural rainstorm of 61 mm (2.4 in) following the 60-minute storm. The synthesis, based on soil content and infiltration data (Figure 48) from the simulated rainstorms, introduced some uncertainty in the acquired soil-loss values. On the other hand, the consistency in these basic data and good reproducibility between replicates for the 60-minute storm gave credence to the derived soil loss values for the 30-minute storms. Furthermore, it should be noted that in computations of soil erodibility, the influence of the soil loss measurements of the 60-minute storm appreciably outweighed those of the 30-minute storms.

The tilled treatment of the Mayberry subsoil differed from that of the Wymore subsoil in that the soil was less friable. In fact, for the tilled treatment, even following a final disking, a large degree of non-uniformity in clod sizes was retained (Figures 49 and 50). The soil did not readily slake or break down as was observed with the Pawnee subsoil. In fact, 188 mm (7.4 inches) of rain left a soil surface with a considerable degree of roughness (Figures 51 and 52) causing reduced runoff velocities and soil loss. Clods disintegrated to some extent into small aggregates (Figure 52), which were either deposited in voids or carried by the runoff water.

The tremendous stability of the individual aggregates was also apparent in the scalped treatment (Figures 53 and 54). One day after the conclusion of the rainulator tests, the soil still looked like an agglomerate of stable aggregates (Figure 54). Again, the stability of these aggregates is not well understood, but is presumably related to their chemical composition.

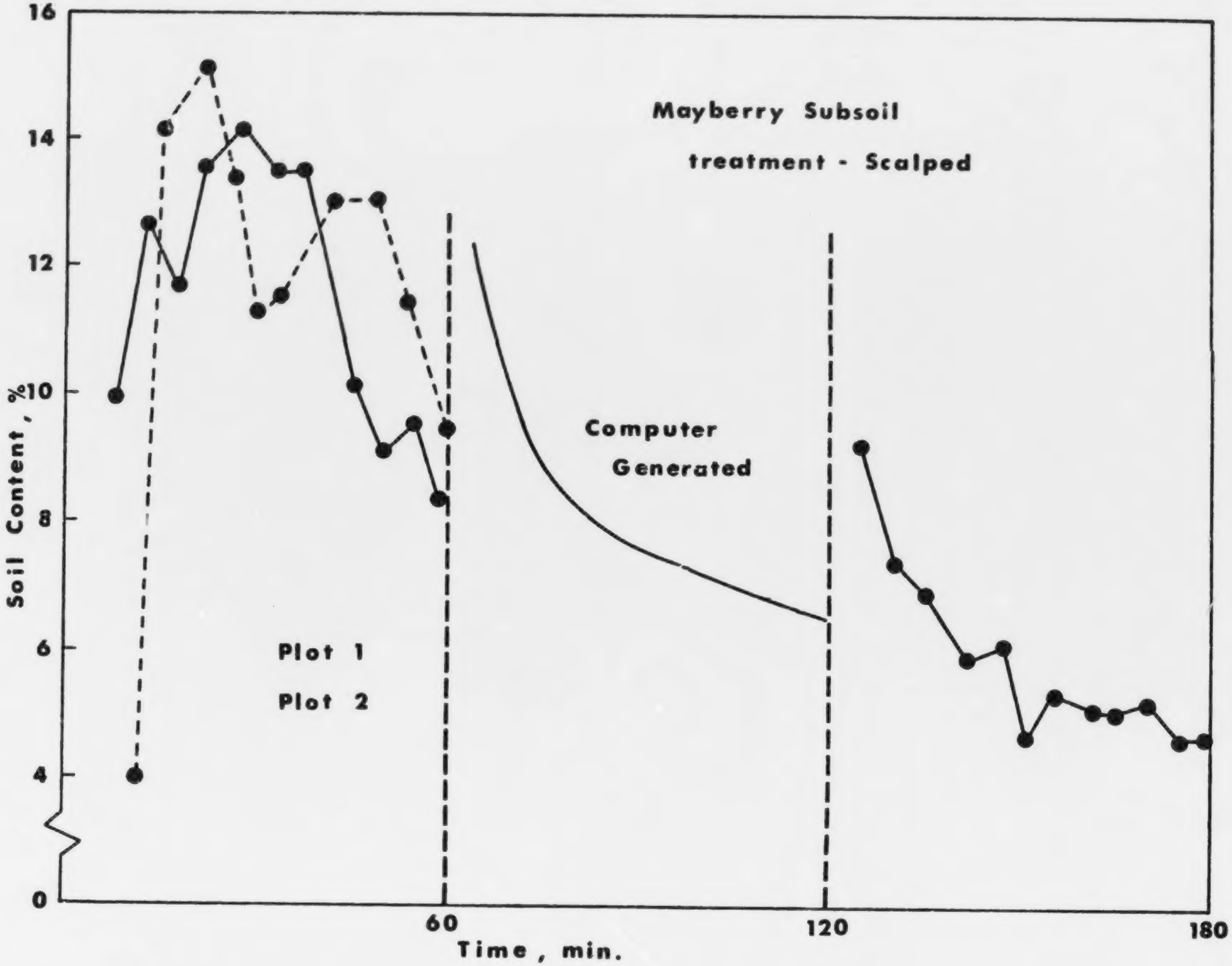


Figure 48. Soil content in runoff from the scalped treatment on the Mayberry subsoil.

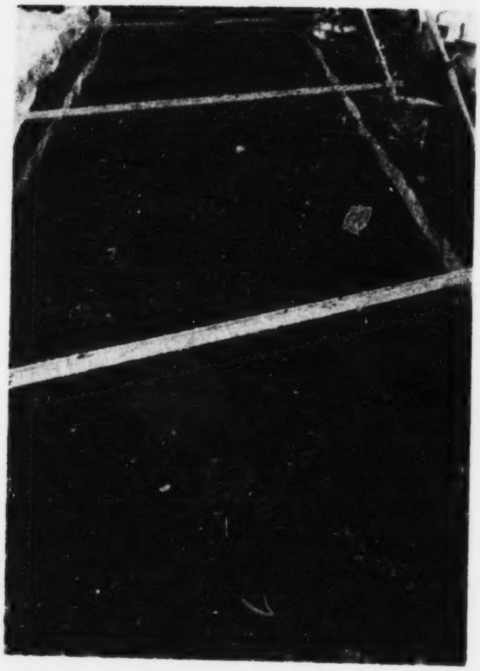


Figure 49. Plot view of the tilled treatment on Mayberry subsoil before rainstorm tests.

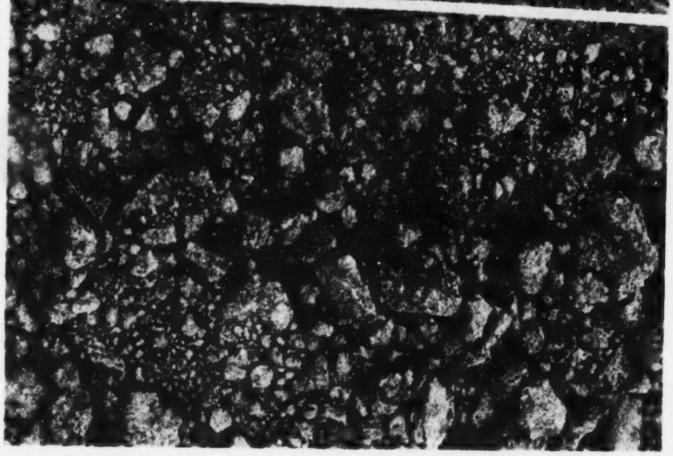


Figure 50. Close-up view of the tilled treatment on Mayberry subsoil before rainstorm tests.

Figure 51. Plot view of the tilled treatment on Mayberry subsoil after 188 mm (7.4 inches) of rain.

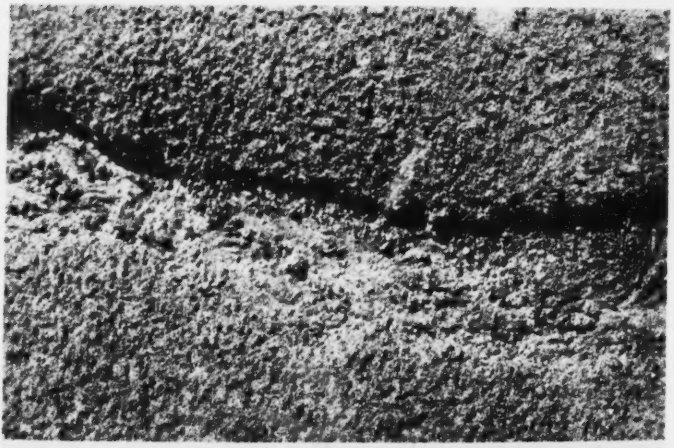


Figure 52. Close-up view of the tilled treatment on Mayberry subsoil after 188 mm (7.4 inches) of rain.

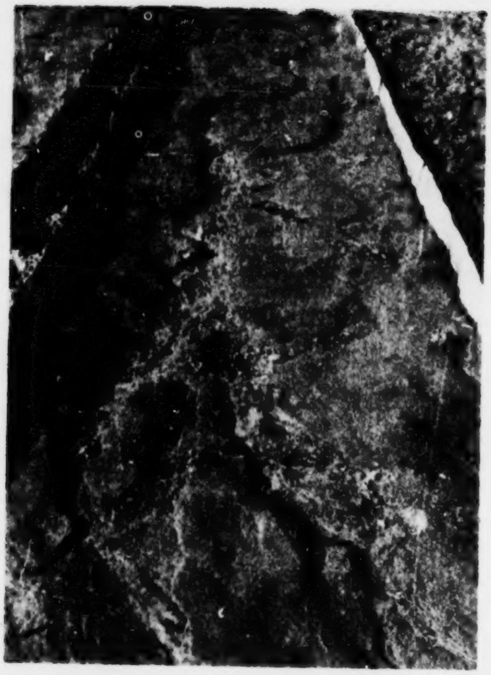


Figure 53. Plot view of the scalped treatment on Mayberry subsoil after 188 mm (7.4 inches) of rain.

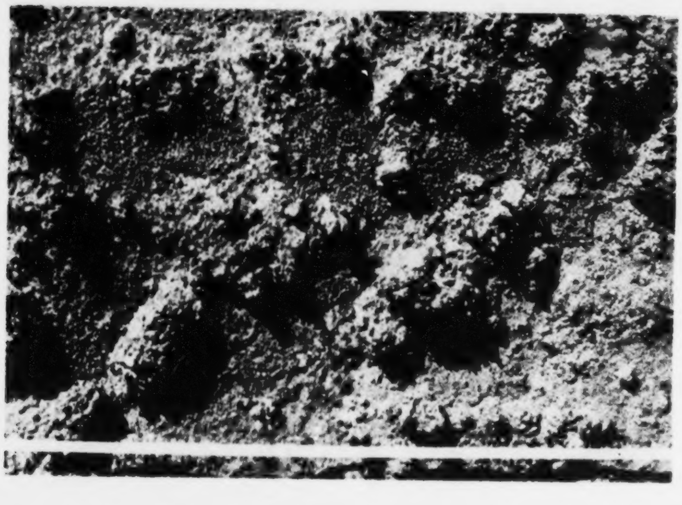


Figure 54. Close-up view of the scalped treatment on Mayberry subsoil after 188 mm (7.4 inches) of rain.

Most of the soil removed from the Mayberry scalped-treatment plot appears to have originated from rills (Figure 53). The bulk of runoff sediment consisted of aggregates. The significance of this observation is that high soil erosion rates from a weathered and well aggregated subsoil like the Mayberry, and to some extent also the Wymore subsoil, is a recurrent phenomenon following drying. It appears that particle size and the degree of interaggregate bonding may be important parameters in soil erosion problems of high clay subsoils.

## COMPUTATION OF SOIL ERODIBILITY FACTOR, K

In computing the soil erodibility factor, K, soil loss measurements for each storm and treatment were adjusted to standard conditions of 9-percent slope steepness and 72.6 feet slope length using relationships given by Wischmeier and Smith (1965). The cropping-management factor, C, and erosion-control practice factor, P, were taken to be 1. K-values could then be computed as the average soil-loss per unit of R, where R represents the number of erosion-index units for a given storm as defined in the Universal Soil Loss Equation. So that the K values computed from the simulated rainstorms would more nearly represent the storm size distribution of natural rain, average soil losses per unit of R were computed for combinations of thirteen 63.5 mm (2.5 in) rains on moderately dry soil, four 31.75 mm (1.25 in) rains on wet soil, and three 63.5 mm (2.5 in) rains on wet soil (Wischmeier et al., 1971). This approach minimized the influence of variations in antecedent moisture and reflected annual rainfall pattern in the geographical area where tests were conducted. To further adjust for differences in rainfall energy between a natural rainstorm and the simulated rainstorm, both of 63.5 mm (2.5 in) per hour rainfall intensity, the weighted soil erodibility factor was multiplied by a factor 0.8 (Meyer and McCune, 1958). A summary of the observed erodibility factors, $K_{obs}$, and the nomograph derived erodibility factors, $K_{nomo}$ (Wischmeier, et al., 1971), using physical and chemical parameters determined from soil profile descriptions and laboratory analyes, is given in Tables 4 and 5 for the tilled and scalped conditions, respectively.

Table 4. OBSERVED AND PREDICTED SOIL ERODIBILITY FACTORS FOR TILLED SUBSOILS

| Soil | Soil ID number | Kobs | Total[a] organic carbon % | Organic[a] matter % | Sand[b] (>100μ), % | Silt[b] (2-100μm), % | Struc-[c] ture | Perme-[c] ability | Knomo[d] |
|---|---|---|---|---|---|---|---|---|---|
| McGary | 191E | 0.17 | 0.34 | 0.54 | 0.46 | 59.05 | 4 | 6 | 0.43 |
| Portageville | 192E | 0.01 | 1.23 | 2.12 | 0.00 | 32.15 | 4 | 6 | 0.19 |
| St. Clair | 212E | 0.31 | 0.75 | 1.29 | 9.80 | 48.82 | 4 | 6 | 0.34 |
| Wymore | 210E | 0.03 | 0.92 | 1.58 | 2.01 | 53.45 | 4 | 6 | 0.34 |
| Pawnee | 206E | 0.24 | 0.82 | 1.41 | 20.56 | 38.68 | 4 | 6 | 0.29 |
| Mayberry | 208E | 0.04 | 0.82 | 1.41 | 7.56 | 54.18 | 4 | 6 | 0.37 |

[a] Determination according to Mebius (1960). Conversion factor for organic carbon to organic matter was taken to be 1.72.

[b] Procedures described in section V.

[c] Evaluations were made from soil profile descriptions.

[d] Soil erodibility factor, K, as determined from the nomograph of Wischmeier et al., 1971.

Table 5. OBSERVED AND PREDICTED SOIL ERODIBILITY FACTORS FOR SCALPED SUBSOILS

| Soil | Soil ID number | Kobs | Total[a] organic carbon % | Organic[a] matter % | Sand[b] (>100μ), % | Silt[b] (2-100μm), % | Struc-[c] ture | Perme-[c] ability | Knomo[d] |
|---|---|---|---|---|---|---|---|---|---|
| McGary | 191S | 0.36 | 0.34 | 0.58 | 0.46 | 59.05 | 4 | 6 | 0.43 |
| Portageville | 192S | 0.05 | 1.23 | 2.12 | 0.00 | 32.15 | 4 | 6 | 0.19 |
| St. Clair | 212S | 0.48 | 0.75 | 1.29 | 9.80 | 48.82 | 4 | 6 | 0.34 |
| Wymore | 210S | 0.49 | 0.92 | 1.58 | 2.01 | 53.45 | 4 | 6 | 0.34 |
| Pawnee | 206S | 0.45 | 0.82 | 1.41 | 20.56 | 38.68 | 4 | 6 | 0.29 |
| Mayberry | 208S | 0.67 | 0.82 | 1.41 | 7.56 | 54.18 | 4 | 6 | 0.37 |

[a] Determinations according to Mebius (1960). Conversion factor for organic carbon to organic matter was taken to be 1.72.

[b] Procedures described in section V.

[c] Evaluations were made from soil profile descriptions.

[d] Soil erodibility factor, K, as determined from the nomograph of Wischmeier et al., 1971.

Significant differences were obtained between $K_{obs}$ and $K_{nomo}$ for both the tilled and scalped subsoils. The $K_{obs}$ values derived from the tilled treatments for all subsoils were consistently smaller than the $K_{nomo}$ values, while $K_{obs}$ from the scalped treatment for all but the McGary and Portageville subsoils were appreciably larger than the $K_{nomo}$. The magnitude of the differences raises doubt about the accuracy of the nomograph as derived by Wischmeier et al. (1971) in soil erosion predictions from subsoils - at least from high clay subsoils. Some uncertainty exists, however, concerning the proper interpretation of the structure and permeability parameters for subsoils. By equating the tilled treatments with permeable surface soils underlain by massive clay (storage taken to be similar to high intake rates) it may be argued that the permeability factor for some subsoils should be assigned a value 5 or perhaps even 4. In that case the $K_{nomo}$ values should be reduced by 0.03 or 0.06 units. Such a correction would improve the erodibility factor prediction but significant discrepancies with the $K_{obs}$ values would remain. Only the predictions for the Pawnee and St. Clair subsoils would approach the $K_{obs}$ values for those subsoils. Similarly, the soil structure of the weathered scalped subsoils could, in some cases (Mayberry), be assigned the value 3. Again, no significant improvement in erodibility predictions would be obtained. In fact, the new predictions might enhance the discrepancy (Mayberry).

A summary of the observed and predicted erodibility factors for surface soils, including those of the Nebraska sites studied in this project, has been given in Table 6. The procedures used for these determinations have been outlined by Wischmeier et al., (1971). The cropping management factors used for the Wymore, Pawnee and Mayberry topsoils were based on the cropping history of the sites.

## SELECTION OF STANDARD CONDITION FOR SUBSOIL ERODIBILITY FACTOR DETERMINATION

Subsoil erodibility determinations often involve soil conditions different than those on surface soils. Subsoils are usually free of plant residues, which would relax, if not eliminate, the suggested two-year

### Table 6. OBSERVED AND PREDICTED SOIL ERODIBILITY FACTORS FOR SURFACE SOILS

| Soil name | Sample ID number | Soil erodibility factor[a] | |
|---|---|---|---|
| | | Knomo | Kobs |
| Bedford | 101 | .46 | .46 |
| | 103 | .39 | .39 |
| Bewleyville | 104 | .36 | .39 |
| Cincinnati | 105 | .52 | .54 |
| Muren | 106 | .42 | .43 |
| Russell | 112 | .44 | .42 |
| Rossmoyne | 114 | .51 | .55 |
| Switzerland | 115 | .41 | .40 |
| | 117 | .47 | .51 |
| | 119 | .45 | .43 |
| Parr | 121 | .30 | .33 |
| Morley | 123 | .30 | .26 |
| Miami | 125 | .26 | .22 |
| Miami | 126 | .24 | .25 |
| Fox | 128 | .28 | .28 |
| | 131 | .24 | .25 |
| | 133 | .41 | .42 |
| Princeton | 135 | .08 | .07 |
| Princeton | 140 | .50 | .39 |
| Princeton | 144 | .08 | .07 |
| Pembroke | 145 | .53 | .54 |
| Morley | 147 | .31 | .25 |
| Elkinsville | 149 | .41 | .42 |
| Varna | 150 | .29 | .27 |
| Frederick | 152 | .43 | .39 |
| Morley | 154 | .38 | .37 |
| Russell | 155 | .44 | .48 |
| Ockley | 157 | .39 | .41 |
| Grayford | 160 | .51 | .58 |
| Miami | 162 | .32 | .36 |
| Warsaw | 164 | .13 | .11 |
| Zanesville | 166 | .52 | .52 |
| Marlove | 168 | .34 | .36 |
| Markland | 169 | .22 | .20 |
| Zanesville | 170 | .40 | .36 |
| Celina | 171 | .26 | .24 |
| Celina | 172 | .38 | .34 |
| Morley | 174 | .48 | .47 |
| Wea | 176 | .24 | .26 |
| Parr | 178 | .24 | .25 |
| Fox | 179 | .09 | .09 |
| Morley | 180 | .37 | .38 |
| Avonburg | 182 | .54 | .55 |
| Pawnee Topsoil | 207 | .28 | .37 |
| Mayberry Topsoil | 209 | .31 | .31 |
| Wymore Topsoil | 211 | .32 | .34 |

[a] Knomo is the K factor derived from the soil erodibility nomograph developed by Wischmeier et al.(1971) and Kobs is the K factor actually measured.

requirement for decomposition of plant material before erodibility measurements can be made. On the other hand, subsoils have had much less exposure to processes of natural weathering, that is drying and wetting, than surface soils. This consideration suggests an extended fallow period upon removal of the overburden soil. Hence, a straightforward application of techniques developed for surface soils may not be appropriate for determining the erodibility factor of subsoils. The poor predictions for the erodibility factor of high clay subsoils from both tilled and scalped surface conditions seems to confirm this notion. Therefore, it would seem justified to select standard conditions for subsoil erodibility measurements which may constitute a better basis for future erodibility predictions. The following reasons led to the selection of the scalped surface as a more suitable standard surface condition on high clay subsoils for erodibility measurements:

1. Scalped surfaces are more commonly found on construction sites.
2. Scalped surfaces are more reproducible than tilled soil.
3. Variations in void volume and thus storage capacity at different locations and within replicates of a given location are minimized.

Because of these considerations, the observed soil erodibility factors, $K_{obs}$, chosen for further analysis in the statistical phase of this project are those derived from the scalped treatment. It could be argued then that the ratio $K_{obs}$(tilled)/$K_{obs}$ (scalped) represents in fact the soil-management factor. This factor is smaller than 1 for all subsoils tested. Assuming that the basic format of the Universal Soil-Loss Equation also holds for subsoils, the cropping-management factor in this equation should then be replaced by the soil-management factor. In arriving at the soil erodibility factor for subsoils it should be stressed that a further refinement for the standard plot condition will be needed especially in regard to the degree of weathering. Also, the above considerations should not be interpreted as negating the existing nomograph (Wischmeier et al., 1971) for all subsoils. Medium textured subsoils may follow the soil erodibility factor predictions of the nomograph developed by Wischmeier et al. (1971).

# V. LABORATORY CHARACTERIZATION OF REFERENCE SOILS FOR PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES

To arrive at relationships between the erodibility factor, K, determined in field experiments, and the specific physical, chemical, and mineralogical properties of soils, it was necessary to carry out extensive laboratory analyses of reference soils. Wischmeier and Mannering (1969) had previously used organic matter content, a variety of particle size parameters, and other physical properties to empirically predict the erodibility factor for surface soils. Later Wischmeier et al. (1971) developed a nomograph utilizing five parameters (% silt plus very fine sand, % sand, organic matter content, structure, and permeability) to estimate the soil erodibility factor of surface and subsoils. Their model was based on analyses of 55 surface soils.

Intuitively, intrinsic soil properties must control soil erodibility. However, selection of the soil properties to be quantitatively measured is difficult due to the large number of soil factors which may affect erodibility either directly or indirectly. We decided that measurement of basic soil constituents and properties was the best hope for improvement in the prediction of the soil erodibility factor and further that nonquantitative, subjective parameters should be avoided if possible. The soil parameters measured were those which are known to influence soil erodibility or have been reported to play some role in soil aggregation processes.

## SAMPLING AND SOURCE OF SOIL SAMPLES

Forty-three of the surface soil samples considered in this study were part of the 55 soil samples used by Wischmeier et al. (1971 ) in development of the nomograph to predict erodibility of surface soils. The other twelve soils used by Wischmeier could not be used in this study because of insufficient amount of sample. When received, the soil samples had been air-dried, ground to 2-mm and stored in paper bags since they were collected between 1961 and 1965. Three additional surface soils were collected as a part of this project during field studies near Syracuse, Nebraska.

One subsoil sample was obtained from Agricultural Research Service Soil Erosion Group at Purdue University. The remaining six subsoil samples were collected at the site on which field studies of soil erodibility were conducted as a part of this project.

The soil samples collected as a part of this study represented a composite of several individual samples (0-15 cm depth) taken from the actual rainulator plots. The composited samples were air-dried at room temperature (25°C), ground to pass a 2-mm screen, and stored in sealed plastic bags. A subsample was removed and ground to pass a 80 mesh sieve for use in certain chemical analyses. Finely ground samples were stored in glass vials. All analyses given are the average of at least duplicate determinations and are reported on a moisture-free basis.

## DETERMINATION OF PHYSICAL PROPERTIES

Particle size analysis of samples was performed using the basic procedure outlined by Jackson (1956). The soil samples were dispersed with a sodium carbonate solution after removal of carbonates, soluble salts, and divalent cations with sodium acetate buffer (pH 5), removal of organic matter with hydrogen peroxide, and removal of iron oxides with sodium citrate-bicarbonate-dithionite solution. The sand and coarse silt (> 20μm diameter) particles were separated from the dispersed soil sample by gravity sedimentation. The sand and coarse silt material was then separated into standard size fractions by dry-sieving in a nest of sieves. The fine silt (2-20μm diameter) was separated from the clay (<2μm) by centrifuge sedimentation.

The amounts of fine and coarse silt were combined to give a value for total silt as were the fine sand fractions to give total sand. Summation of the values for sand, silt, and clay does not yield 100% due to removal of carbonates, iron oxides, and organic matter in the dispersion process. A "new" silt parameter was also calculated by adding the amount of very fine sand (50 to 100μm diameter) to the silt value to give a value for the total soil particles having a mean diameter between 2 and 100μm. Computation of a "new" silt parameter also resulted in a "new" sand parameter involving particles with diameters between 100 and 2000μm. These calculations merely involved transfer of the very fine sand component from the sand fraction to the silt fraction. A particle size factor, M, which Wischmeier et al. (1971) found to be highly related to soil erodibility, was also calculated. The M factor was computed by multiplying the "new" silt percentage by the sum of "new" silt and "new" sand.

Soil structure and permeability classes were coded from information in soil profile descriptions made at the rainulator sites as described by Wischmeier et al. (1971). The permeability classes refer to the soil profile as a whole. Both soil structure and permeability are somewhat subjective parameters which depend upon the accuracy of the soil profile description.

Table 7 provides data on the physical parameters determined for each soil in the study. It is evident that the soils studied represent a wide range in sand, silt, and clay contents and vary widely in structure, permeability and textural classification. Six of the seven subsoils analyzed contain in excess of 33% clay and as a group the subsoils have a good range in sand and silt contents. However, all of the subsoils were considered to have blocky or massive structure (coded 4), and very slow permeability (coded 6).

## DETERMINATION OF CHEMICAL COMPONENTS

The reference soil samples were analyzed for a variety of chemical constituents. A sodium citrate-bicarbonate-dithionite (CDB) extraction to remove iron oxides was performed on soil samples as outlined in Appendix B. The CDB extraction procedure removes crystalline and noncrystalline iron oxides except highly crystalline hematite and magnetite and also removes aluminum hydrous oxides and hydrous silica associated with iron oxides in soils (Roth et al., 1969). Iron, aluminum, and silicon in the CDB extract were determined colorimetrically as outlined in Appendix B and are reported as citrate-dithionite extractable iron oxide, aluminum oxide, and silica.

Organic carbon was determined in soils by the procedure of Mebius (1960) using < 80-mesh samples. Sodium pyrophosphate extractable organic carbon and hot water extractable organic carbon were determined by the procedures given in Appendix B. An index of the amounts of polysaccharides present in soils was obtained by reacting the samples with sodium periodate and measuring the decrease in periodate concentration after 24 hours as described in Appendix B. Total organic carbon and extractable organic carbon are reported as percent of soil on a weight basis and the index of polysaccharides is given as millimoles of periodate consumed per gram of soil in 24 hours of reaction at room temperature. Total N in soils was estimated by the procedure of Nelson and Sommers (1972) and total P by the method of Sommers and Nelson (1972). Total N and total P are reported as ppm of soil on a weight basis.

Table 8 gives a listing of the chemical constituents of the 46 surface soils and 7 subsoils used in this study. Fairly wide ranges in $Fe_2O_3$, $Al_2O_3$, and $SiO_2$ content were observed, however, the surface soils were somewhat uniform in nitrogen, phosphorus, and carbon content. A wide range in periodate-oxidizable polysaccharides was evident with both surface and subsoils. The subsoils studied had a reasonable range in all chemical parameters measured.

## DETERMINATION OF CLAY MINERALOGICAL COMPONENTS

The clay-sized material originally separated in the particle size analysis procedure was subjected to x-ray diffraction analysis according

## Table 7. PHYSICAL CHARACTERISTICS OF SOILS USED IN THIS STUDY

| Soil | | | Particle size distribution | | | Sand fractions (mm) | | | | | New silt | New sand | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Type[a] | ID No. | clay | silt | sand | 1-2 | .5-1 | 0.5-0.25 | 0.25-0.1 | 0.1-0.05 | 2-100 μm | .1-2mm | M[b] | Structure[c] | Permeability[d] |
| | | | -------% | -------- | | ---------- | ------- | % of sand | ------- | ---------- | -------% | ------- | | | |
| Surface soils: | | | | | | | | | | | | | | | |
| Bedford | SIL | 101 | 15.0 | 69.9 | 10.1 | 5.7 | 6.9 | 5.7 | 38.8 | 42.8 | 74.2 | 5.8 | 5938 | 3 | 4 |
| | SIL | 103 | 20.3 | 67.4 | 7.9 | 5.4 | 14.9 | 29.6 | 20.3 | 41.9 | 70.7 | 4.6 | 5328 | 2 | 4 |
| Bewleyville | SIL | 104 | 14.4 | 76.6 | 4.8 | 18.8 | 26.6 | 10.1 | 15.9 | 30.4 | 78.0 | 3.3 | 6347 | 2 | 3 |
| Cincinnati | SIL | 105 | 18.6 | 73.5 | 2.6 | 15.8 | 18.4 | 15.8 | 18.4 | 31.6 | 74.3 | 1.8 | 5649 | 3 | 6 |
| Muren | SIL | 106 | 19.7 | 71.5 | 4.0 | 9.0 | 7.9 | 5.7 | 7.9 | 69.6 | 74.3 | 1.2 | 5607 | 2 | 3 |
| Russell | SIL | 112 | 13.5 | 56.2 | 27.1 | 2.2 | 10.2 | 22.0 | 35.8 | 29.8 | 64.2 | 19.0 | 5347 | 3 | 3 |
| Rossmoyne | SIL | 114 | 16.8 | 71.2 | 8.1 | 6.6 | 15.8 | 19.7 | 27.6 | 30.3 | 73.6 | 5.7 | 5839 | 3 | 6 |
| Switzerland | SIL | 115 | 19.9 | 20.2 | 4.2 | 7.2 | 14.2 | 19.4 | 30.6 | 28.6 | 71.4 | 3.0 | 5314 | 3 | 3 |
| | SIL | 117 | 14.5 | 52.8 | 28.1 | 1.6 | 1.9 | 4.5 | 40.6 | 51.4 | 67.2 | 13.7 | 5439 | 3 | 4 |
| | SIL | 119 | 18.2 | 61.4 | 16.2 | 4.6 | 8.2 | 10.4 | 46.4 | 30.5 | 66.3 | 11.2 | 5138 | 3 | 4 |
| Parr | L | 121 | 19.2 | 46.3 | 28.7 | 6.8 | 15.7 | 22.2 | 32.1 | 23.2 | 53.0 | 22.0 | 3974 | 3 | 3 |
| Morley | CL | 123 | 24.3 | 39.6 | 28.8 | 5.6 | 12.9 | 16.4 | 33.4 | 31.7 | 48.7 | 19.7 | 3333 | 3 | 4 |
| Miami | SL | 125 | 6.1 | 24.0 | 66.9 | 3.1 | 10.7 | 20.1 | 42.0 | 24.6 | 40.5 | 50.4 | 3677 | 3 | 3 |
| Miami | L | 126 | 19.7 | 36.4 | 38.4 | 6.0 | 12.3 | 18.9 | 35.2 | 27.5 | 48.4 | 26.4 | 3616 | 3 | 3 |
| Fox | SIL | 128 | 18.8 | 65.0 | 10.3 | 6.2 | 14.4 | 16.5 | 13.4 | 49.5 | 70.1 | 5.2 | 5284 | 2 | 3 |
| | SICL | 131 | 36.8 | 44.1 | 9.1 | 2.7 | 10.8 | 12.0 | 22.8 | 51.7 | 48.8 | 4.4 | 2597 | 3 | 4 |
| | SIL | 133 | 19.4 | 68.8 | 7.0 | 0 | 7.8 | 7.8 | 34.1 | 50.4 | 72.3 | 3.5 | 5478 | 3 | 3 |
| Princeton | LS | 135 | 3.9 | 8.2 | 86.4 | 0.1 | 5.8 | 37.9 | 47.8 | 8.5 | 15.5 | 79.1 | 1470 | 2 | 2 |
| | SL | 140 | 8.3 | 35.1 | 54.4 | 0.1 | 0.6 | 5.0 | 74.7 | 19.8 | 45.8 | 43.6 | 4101 | 3 | 3 |
| | LS | 144 | 2.6 | 10.1 | 85.6 | 0.7 | 23.4 | 39.0 | 29.0 | 7.9 | 16.9 | 78.9 | 1615 | 2 | 2 |
| Pembroke | SIL | 145 | 15.6 | 76.8 | 3.3 | 6.2 | 12.1 | 5.9 | 17.9 | 57.9 | 78.7 | 1.4 | 6300 | 4 | 5 |
| Morley | CL | 147 | 25.4 | 29.4 | 28.4 | 8.3 | 15.9 | 15.6 | 32.0 | 28.2 | 47.4 | 20.4 | 3211 | 3 | 4 |
| Elkinsville | SIL | 149 | 12.6 | 67.5 | 16.5 | 2.5 | 1.2 | 1.2 | 25.2 | 69.9 | 79.1 | 5.0 | 6641 | 2 | 3 |
| Varna | L | 150 | 15.5 | 48.8 | 31.5 | 4.1 | 11.0 | 27.6 | 39.5 | 17.8 | 54.4 | 25.9 | 4372 | 3 | 4 |
| Frederick | SIL | 152 | 21.8 | 61.7 | 11.6 | 1.5 | 3.9 | 3.9 | 42.8 | 47.8 | 67.3 | 6.1 | 4939 | 3 | 3 |
| Morley | L | 154 | 14.5 | 41.2 | 41.1 | 3.0 | 10.6 | 19.9 | 39.3 | 27.2 | 52.4 | 29.9 | 4309 | 4 | 4 |
| Russell | SIL | 155 | 10.7 | 69.4 | 15.9 | 5.4 | 15.8 | 24.5 | 34.2 | 20.1 | 72.6 | 12.7 | 6186 | 3 | 3 |
| Ockley | SIL | 157 | 11.9 | 54.8 | 29.6 | 12.5 | 29.0 | 29.6 | 21.6 | 7.2 | 57.0 | 27.4 | 4804 | 3 | 3 |
| Grayford | SIL | 160 | 15.5 | 75.9 | 3.7 | 3.4 | 15.5 | 22.4 | 29.3 | 29.3 | 76.9 | 2.6 | 6118 | 4 | 5 |
| Miami | SL | 162 | 7.8 | 27.5 | 61.9 | 3.9 | 11.5 | 21.9 | 40.5 | 22.2 | 41.3 | 48.1 | 3691 | 2 | 4 |
| Warsaw | SL | 164 | 13.2 | 22.5 | 59.3 | 9.8 | 20.4 | 31.9 | 30.4 | 7.5 | 27.0 | 54.8 | 2208 | 3 | 2 |
| Zanesville | SIL | 166 | 17.2 | 72.5 | 6.9 | 4.0 | 9.0 | 7.9 | 22.0 | 57.1 | 76.4 | 2.9 | 6057 | 3 | 6 |

Table 7 (continued). PHYSICAL CHARACTERISTICS OF SOILS USED IN THIS STUDY

| Soil |  |  | Particle size distribution |  |  | Sand fractions (mm) |  |  |  |  | New silt | New sand |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Type[a] | ID No. | clay | silt | sand | 1-2 | .5-1 | 0.5-0.25 | 0.25-0.1 | 0.1-0.05 | 2-100 μm | .1-2mm | M[b] | Scruc-ture[c] | Perme-ability[d] |
|  |  |  | % |  |  | % of sand |  |  |  |  | % |  |  |  |  |
| Marlove | SIL | 168 | 13.4 | 55.5 | 26.9 | 2.4 | 15.4 | 30.4 | 32.0 | 19.8 | 60.8 | 21.6 | 5011 | 2 | 3 |
| Markland | SICL | 169 | 34.9 | 54.1 | 1.8 | 9.1 | 9.1 | 9.1 | 18.2 | 54.5 | 55.1 | 0.8 | 3077 | 3 | 3 |
| Zanesville | SIL | 170 | 17.3 | 64.9 | 13.8 | 0.8 | 1.6 | 0.8 | 28.7 | 68.0 | 74.3 | 4.4 | 5847 | 2 | 3 |
| Celina | SL | 171 | 10.0 | 25.6 | 61.1 | 2.7 | 12.7 | 25.0 | 40.3 | 19.2 | 37.3 | 49.4 | 3238 | 4 | 3 |
| Celina | L | 172 | 19.8 | 49.4 | 27.6 | 2.7 | 6.1 | 15.8 | 34.6 | 40.8 | 60.7 | 16.3 | 4676 | 4 | 4 |
| Morley | SIL | 174 | 11.7 | 59.8 | 24.4 | 8.9 | 13.0 | 16.8 | 32.4 | 28.9 | 66.9 | 17.3 | 5633 | 3 | 4 |
| Wea | SIL | 176 | 17.3 | 62.1 | 15.7 | 3.2 | 12.7 | 22.1 | 29.7 | 32.3 | 67.2 | 10.6 | 5225 | 2 | 3 |
| Parr | L | 178 | 13.2 | 41.4 | 40.1 | 5.2 | 14.1 | 22.3 | 25.7 | 32.6 | 54.5 | 27.0 | 4440 | 2 | 3 |
| Fox | GSL | 179 | 6.9 | 12.5 | 78.1 | 12.9 | 29.8 | 28.9 | 23.0 | 5.4 | 16.7 | 73.9 | 1515 | 2 | 3 |
| Morley | L | 180 | 16.8 | 44.3 | 35.0 | 1.9 | 7.7 | 24.5 | 43.4 | 22.6 | 52.2 | 27.1 | 4138 | 3 | 5 |
| Avonburg | SIL | 182 | 10.3 | 66.1 | 20.3 | 5.3 | 14.1 | 20.6 | 32.9 | 27.2 | 71.6 | 14.8 | 6186 | 3 | 6 |
| Pawnee | SICL | 207 | 36.3 | 41.8 | 16.5 | 3.1 | 6.1 | 17.5 | 30.1 | 38.8 | 48.2 | 10.1 | 2809 | 3 | 5 |
| Mayberry | SICL | 209 | 29.4 | 46.9 | 18.8 | 0.5 | 6.0 | 16.3 | 28.3 | 48.9 | 56.1 | 9.6 | 3685 | 3 | 5 |
| Wymore | SICL | 211 | 37.5 | 53.3 | 6.3 | 4.9 | 11.1 | 7.6 | 8.3 | 68.1 | 57.5 | 2.0 | 3425 | 3 | 5 |
| Subsoils: |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Wingate | SL | 188 | 9.9 | 29.2 | 54.0 | 8.8 | 14.8 | 18.1 | 34.0 | 24.3 | 42.3 | 40.9 | 3514 | 4 | 6 |
| McGary | SIC | 191S | 39.8 | 58.7 | 0.8 | 20.0 | 0 | 20.0 | 20.0 | 40.0 | 59.1 | 0.5 | 3514 | 4 | 6 |
| Portageville | C | 192S | 66.5 | 32.2 | 0.3 | e | e | e | e | e | 32.2 | 0.3 | 1045 | 4 | 6 |
| Pawnee | CL | 206S | 35.4 | 28.6 | 30.7 | 2.7 | 15.0 | 19.7 | 29.6 | 33.0 | 38.7 | 20.6 | 2291 | 4 | 6 |
| Mayberry | SICL | 208S | 33.9 | 47.4 | 14.4 | 2.2 | 10.7 | 14.4 | 25.3 | 47.4 | 54.2 | 7.6 | 3345 | 4 | 6 |
| Wymore | SIC | 210S | 38.5 | 50.8 | 4.7 | 4.9 | 16.8 | 11.9 | 8.9 | 57.4 | 53.5 | 2.0 | 2965 | 4 | 6 |
| St. Clair | SIC | 212S | 38.7 | 43.8 | 14.8 | 2.6 | 16.8 | 21.2 | 25.7 | 33.7 | 48.8 | 9.8 | 2862 | 4 | 6 |

[a] SIL, silty loam; L, loam; CL, clay loam; SL, sandy loam; SICL, silty clay loam; LS, loamy sand; CSL, gravely sandy loam; C, clay; SIC, silty clay.

[b] M=% new silt (% new silt + % new sand).

[c] 1, very fine granular; 2, fine granular; 3, med. or coarse granular, 4, blocky, platy or massive.

[d] 1, rapid; 2, mod. to rapid; 3, moderate; 4, slow to med.; 5, slow; 6, very slow.

[e] Insufficient sand in sample for fractionation.

Table 8. CHEMICAL COMPOSITION OF SOILS USED IN THIS STUDY

| Sample ID Number | Citrate-Dithionite Extractable $Fe_2O_3$ | Citrate-Dithionite Extractable $Al_2O_3$ | Citrate-Dithionite Extractable $SiO_2$ | Total P | Total N | Total C | Pyrophosphate extractable carbon | Hot $H_2O$ extractable carbon | Periodate consumed |
|---|---|---|---|---|---|---|---|---|---|
| | -----------%---------- | | | -------ppm-------- | | ---------------------%--------------------- | | | (mmoles/gm) |
| Surface Soils: | | | | | | | | | |
| 101 | 1.53 | .304 | .051 | 305 | 1120 | 1.06 | .27 | .044 | .257 |
| 103 | 1.61 | .246 | .099 | 352 | 980 | 0.77 | .26 | .029 | .195 |
| 104 | 1.58 | .278 | .054 | 315 | 1350 | 1.25 | .34 | .064 | .261 |
| 105 | 1.81 | .324 | .088 | 298 | 1050 | 0.93 | .22 | .041 | .313 |
| 106 | 2.31 | .333 | .097 | 433 | 950 | 0.84 | .26 | .039 | .262 |
| 112 | 1.06 | .210 | .048 | 482 | 1120 | 1.20 | .30 | .036 | .209 |
| 114 | 1.65 | .290 | .043 | 450 | 990 | 1.28 | .34 | .032 | .228 |
| 115 | 1.97 | .305 | .058 | 290 | 970 | 1.09 | .24 | .031 | .212 |
| 117 | 1.55 | .272 | .048 | 273 | 1470 | 0.94 | .22 | .029 | .214 |
| 119 | 1.94 | .318 | .066 | 485 | 1100 | 0.76 | .22 | .032 | .191 |
| 121 | 1.50 | .254 | .097 | 420 | 1630 | 1.86 | .38 | .067 | .338 |
| 123 | 2.08 | .288 | .112 | 750 | 1720 | 1.72 | .31 | .053 | .365 |
| 125 | 0.69 | .157 | .033 | 287 | 1050 | 1.26 | .35 | .053 | .194 |
| 126 | 1.83 | .257 | .100 | 446 | 1130 | 1.29 | .31 | .051 | .284 |
| 128 | 1.65 | .241 | .095 | 482 | 1330 | 1.38 | .35 | .057 | .339 |
| 131 | 3.01 | .398 | .114 | 676 | 1230 | 1.05 | .26 | .043 | .516 |
| 133 | 1.96 | .324 | .094 | 529 | 1330 | 1.25 | .27 | .047 | .394 |
| 135 | 0.73 | .135 | .046 | 375 | 490 | 0.78 | .19 | .020 | .116 |
| 140 | 0.96 | .139 | .053 | 303 | 680 | 0.49 | .21 | .033 | .147 |
| 144 | 0.58 | .088 | .030 | 305 | 460 | 0.31 | .18 | .029 | .098 |
| 145 | 1.60 | .260 | .067 | 447 | 1150 | 0.96 | .28 | .041 | .319 |
| 147 | 2.02 | .246 | .129 | 425 | 1170 | 1.03 | .24 | .038 | .564 |
| 149 | 1.31 | .252 | .065 | 371 | 970 | 0.88 | .27 | .043 | .277 |
| 150 | 1.20 | .242 | .081 | 381 | 1440 | 1.38 | .47 | .064 | .277 |
| 152 | 2.07 | .377 | .071 | 891 | 1400 | 1.01 | .29 | .048 | .356 |
| 154 | 1.33 | .226 | .071 | 257 | 1010 | 1.16 | .32 | .055 | .213 |
| 155 | 1.09 | .198 | .061 | 358 | 1300 | 1.38 | .41 | .065 | .276 |
| 157 | 1.22 | .189 | .061 | 471 | 1350 | 1.17 | .36 | .044 | .323 |

Table 8 (continued). CHEMICAL COMPOSITION OF SOILS USED IN THIS STUDY

| Sample ID Number | Citrate-Dithionite Extractable $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | Total P | Total N | Total C | Pyrophosphate extractable carbon | Hot $H_2O$ extractable carbon | Periodate consumed |
|---|---|---|---|---|---|---|---|---|---|
| | ----------%---------- | | | -------ppm-------- | | --------------------%-------------------- | | | (mmoles/gm) |
| 160 | 1.42 | .248 | .070 | 566 | 1900 | 1.50 | .39 | .059 | .444 |
| 162 | 1.05 | .173 | .058 | 257 | 830 | 0.71 | .27 | .049 | .187 |
| 164 | 1.39 | .260 | .080 | 427 | 1590 | 1.61 | .53 | .090 | .294 |
| 166 | 2.19 | .305 | .094 | 483 | 830 | 0.63 | .25 | .036 | .241 |
| 168 | 1.20 | .198 | .086 | 387 | 1290 | 1.24 | .37 | .054 | .281 |
| 169 | 2.32 | .385 | .095 | 733 | 2240 | 2.09 | .45 | .073 | .644 |
| 170 | 1.76 | .304 | .067 | 308 | 1090 | 0.98 | .26 | .037 | .295 |
| 171 | 1.02 | .160 | .054 | 231 | 920 | 0.90 | .28 | .066 | .213 |
| 172 | 1.81 | .255 | .090 | 303 | 940 | 0.83 | .30 | .044 | .197 |
| 174 | 1.15 | .213 | .072 | 303 | 1310 | 1.39 | .40 | .062 | .289 |
| 176 | 1.39 | .236 | .112 | 590 | 1670 | 1.75 | .48 | .081 | .358 |
| 178 | 1.22 | .175 | .090 | 887 | 1360 | 1.72 | .38 | .057 | .577 |
| 179 | 1.08 | .141 | .054 | 300 | 630 | 0.69 | .23 | .045 | .184 |
| 180 | 1.43 | .216 | .073 | 335 | 850 | 0.69 | .24 | .028 | .168 |
| 182 | 1.06 | .226 | .053 | 300 | 900 | 0.83 | .26 | .036 | .241 |
| 207 | 1.08 | .232 | .185 | 762 | 620 | 2.04 | .41 | .141 | .356 |
| 209 | 1.00 | .220 | .135 | 593 | 500 | 1.31 | .31 | .129 | .275 |
| 211 | 0.93 | .178 | .255 | 1016 | 650 | 1.80 | .38 | .102 | .367 |
| Subsoils: | | | | | | | | | |
| 188 | 2.09 | .194 | .156 | 372 | 410 | 0.53 | [a] | [a] | [a] |
| 191S | 3.52 | .242 | .121 | 516 | 540 | 0.34 | .04 | .020 | .124 |
| 192S | 1.42 | .145 | .265 | 767 | 970 | 1.23 | .38 | .018 | .259 |
| 206S | .85 | .121 | .264 | 800 | 140 | 0.82 | .12 | .117 | .305 |
| 208S | 1.15 | .229 | .127 | 412 | 300 | 0.82 | .18 | .056 | .220 |
| 210S | 0.80 | .293 | .319 | 1018 | 200 | 0.92 | .22 | .097 | .249 |
| 212S | 2.34 | .250 | .155 | 1130 | 180 | 0.75 | .06 | .080 | 1.056 |

[a] Insufficient sample was available to run these analyses.

## Table 9. CLAY MINERALOGICAL COMPOSITION OF SOILS USED IN THIS STUDY (percent of the clay fraction)

| Sample ID No. | Vermiculite | Mica | Kaolinite plus halloysite | Amorphous material | Montmorillonite | Quartz plus feldspar | Chlorite |
|---|---|---|---|---|---|---|---|
| Surface soils: | | | | | | | |
| 101 | 1.5 | 19.4 | 20.3 | 10.6 | 11.0 | 12.5 | 24.7 |
| 103 | 2.0 | 23.2 | 11.6 | 9.9 | 21.3 | 9.3 | 22.7 |
| 104 | 2.1 | 6.7 | 14.9 | 9.1 | 9.9 | 13.0 | 44.3 |
| 105 | 1.2 | 21.1 | 18.8 | 12.0 | 16.6 | 9.1 | 21.2 |
| 106 | 2.6 | 21.9 | 13.6 | 7.7 | 23.0 | 6.3 | 24.9 |
| 112 | 0.0 | 24.8 | 16.9 | 13.4 | 12.5 | 13.5 | 18.9 |
| 114 | 0.0 | 19.8 | 17.3 | 10.5 | 12.3 | 11.8 | 28.3 |
| 115 | 0.1 | 20.1 | 17.7 | 11.8 | 13.2 | 9.9 | 27.2 |
| 117 | 0.7 | 19.2 | 23.5 | 10.0 | 10.3 | 9.7 | 26.6 |
| 119 | 1.2 | 17.3 | 18.4 | 10.4 | 12.1 | 9.0 | 31.7 |
| 121 | 0.8 | 29.2 | 9.2 | 11.7 | 9.2 | 13.5 | 26.3 |
| 123 | 2.9 | 30.4 | 10.0 | 7.0 | 14.9 | 8.7 | 26.1 |
| 125 | 3.1 | 36.1 | 12.5 | 8.8 | 4.5 | 16.1 | 19.0 |
| 126 | 0.5 | 31.1 | 12.6 | 9.2 | 15.6 | 6.9 | 24.1 |
| 128 | 0.0 | 23.4 | 14.7 | 10.6 | 18.3 | 8.3 | 24.7 |
| 131 | 3.2 | 41.7 | 8.3 | 5.0 | 11.0 | 6.4 | 24.4 |
| 133 | 0.3 | 18.8 | 18.5 | 17.3 | 23.3 | 8.5 | 13.3 |
| 135 | 0.1 | 23.3 | 17.1 | 17.6 | 18.2 | 13.7 | 9.9 |
| 140 | 0.0 | 23.6 | 15.0 | 16.7 | 16.9 | 12.6 | 15.1 |
| 144 | 0.0 | 23.1 | 12.9 | 11.7 | 1.4 | 26.7 | 24.2 |
| 145 | 1.7 | 22.1 | 14.5 | 18.5 | 20.1 | 11.0 | 12.1 |
| 147 | 4.4 | 43.2 | 6.0 | 5.8 | 12.9 | 9.3 | 18.4 |
| 149 | 1.6 | 21.8 | 16.8 | 18.3 | 18.8 | 10.2 | 12.5 |
| 150 | 1.1 | 37.2 | 8.4 | 14.8 | 3.4 | 15.8 | 19.3 |
| 152 | 2.3 | 17.2 | 20.0 | 27.6 | 20.9 | 8.4 | 3.7 |
| 154 | 5.2 | 36.4 | 10.0 | 13.7 | 15.7 | 10.0 | 8.9 |
| 155 | 3.2 | 24.0 | 11.8 | 15.1 | 19.0 | 14.8 | 12.1 |
| 157 | 9.7 | 24.2 | 14.2 | 18.8 | 10.5 | 13.2 | 9.4 |
| 160 | 10.0 | 24.3 | 18.3 | 20.5 | 3.7 | 11.2 | 12.1 |
| 162 | 9.6 | 31.5 | 11.1 | 12.3 | 6.4 | 11.4 | 17.8 |
| 164 | 10.7 | 25.3 | 13.6 | 15.7 | 8.1 | 16.5 | 10.2 |
| 166 | 16.9 | 22.0 | 15.7 | 15.6 | 4.4 | 6.1 | 19.3 |
| 168 | 9.4 | 20.0 | 12.1 | 12.6 | 10.8 | 11.8 | 23.4 |
| 169 | 8.2 | 50.4 | 9.6 | 7.0 | 2.1 | 8.6 | 14.1 |
| 170 | 11.4 | 15.5 | 16.5 | 17.7 | 7.6 | 8.8 | 22.5 |
| 171 | 8.8 | 29.6 | 11.9 | 12.7 | 6.7 | 11.3 | 19.1 |
| 172 | 7.4 | 37.7 | 10.4 | 11.3 | 10.6 | 11.1 | 11.5 |
| 174 | 3.7 | 44.1 | 8.6 | 9.9 | 11.3 | 16.2 | 6.4 |
| 176 | 10.2 | 27.5 | 12.2 | 19.0 | 14.2 | 11.9 | 5.0 |
| 178 | 1.9 | 37.1 | 11.7 | 15.8 | 19.9 | 11.1 | 2.5 |
| 179 | 6.5 | 18.4 | 13.4 | 18.9 | 19.0 | 14.2 | 9.5 |

Table 9 (continued). CLAY MINERALOGICAL COMPOSITION OF SOILS USED IN THIS STUDY

(percent of the clay fraction)

| Sample ID No. | Vermi-culite | Mica | Kaolinite plus halloysite | Amorphous material | Montmo-rillonite | Quartz plus feldspar | Chlo-rite |
|---|---|---|---|---|---|---|---|
| 180 | 4.7 | 35.0 | 6.9 | 11.8 | 14.6 | 13.5 | 13.5 |
| 182 | 2.4 | 15.8 | 17.7 | 15.9 | 16.7 | 13.2 | 16.7 |
| 207 | 17.3 | 18.6 | 12.4 | 17.6 | 25.6 | 6.6 | 2.0 |
| 209 | 12.7 | 21.6 | 14.4 | 18.9 | 14.1 | 6.2 | 12.1 |
| 211 | 4.1 | 24.8 | 18.8 | 16.6 | 22.3 | 10.3 | 3.2 |
| Subsoils: | | | | | | | |
| 188 | 4.3 | 53.9 | 7.1 | 6.2 | 11.4 | 11.9 | 5.3 |
| 191S | 5.3 | 37.2 | 8.9 | 9.2 | 19.4 | 6.3 | 13.7 |
| 192S | 7.7 | 23.0 | 9.8 | 9.3 | 22.6 | 7.9 | 19.8 |
| 206S | 12.2 | 16.5 | 12.9 | 13.4 | 30.0 | 8.7 | 6.3 |
| 208S | 7.1 | 20.1 | 14.8 | 15.9 | 28.6 | 6.0 | 7.5 |
| 210S | 12.4 | 22.0 | 9.4 | 11.1 | 30.4 | 7.0 | 7.8 |
| 212S | 5.2 | 45.0 | 9.1 | 10.4 | 5.7 | 13.9 | 10.7 |

to procedures outlined by Jackson (1956) to provide a qualitative estimate of clay mineral composition. The x-ray diffraction studies revealed that the clay fraction of almost every soil contained montmorillonite, kaolinite, mica (illite), vermiculite, quartz, feldspar, and chlorite. In addition, previous studies have shown that the <2μm fraction of soils contain variable amounts of amorphous inorganic material, e.g. allophane, which is not detected by x-ray diffraction techniques. Accordingly, the clay-sized fraction (<2μm mean diameter) of soils in this study was analyzed quantitatively for amorphous and crystalline components. Montmorillonite and vermiculite were determined by the procedure of Alexiades and Jackson (1965) as modified by Chapman (1970). Amorphous material and kaolinite plus halloysite were estimated by the procedures described by Hashimoto and Jackson (1960). Mica and quartz plus feldspar were determined by the procedures given in Appendix B which was modified from Jackson, 1956. Chlorite was estimating by summing the percent of the clay fraction composed of montmorillonite, vermiculite, kaolinite plus halloysite, mica, amorphous materials, and quartz plus feldspar and subtracting the sum from 100. Clay mineral components are reported in Table 9 as percentages of the clay fraction, however, in statistical analyses the clay mineral components were used as percentages of the whole soil on a weight basis.

Table 9 shows that substantial variation exists in the clay mineralogical composition of the surface soils studied. Subsoils tended to contain somewhat higher amounts of vermiculite and montmorillonite and lower amounts of chlorite as compared to surface soils. However, a reasonable range in clay mineralogical composition was observed in subsoil samples.

# VI. STATISTICAL ANALYSIS OF DATA OBTAINED IN FIELD AND LABORATORY EXPERIMENTS

## STATISTICAL PROGRAMS USED

The majority of the statistical analyses on this project were performed using the procedures found in the SPSS (Statistical Package for the Social Sciences) manual (Nie, Bent and Hull, 1970). In particular the REGRESSION procedure was used from the SPSS package of statistical programs. An option in this procedure allows the user to specify that the entrance of variables into the multiple linear regression model will follow the forward selection technique (Draper and Smith, 1966) such that the variable, not already included in the model, which exhibits the highest partial correlation, will be the next forced into the model.

The "weighted regression analysis program" (WRAP) was valuable in certain phases of the statistical analysis portion of this project. This program performs multiple linear regression analysis using the backward elimination technique (Draper and Smith, 1966) in which all the independent variables are forced into the model and subsequently deleted at each state until all variables remaining are significant at the user defined probability level. WRAP differs from the SPSS program in that the latter uses a forward selection technique whereas the former uses a backward elimination technique. The WRAP contains a useful option which allows each observation or case to be weighted by a function of its variance, whereas, the SPSS programs do not contain this option.

Several other techniques and programs were evaluated as to usefulness in the statistical analysis phase of this project but none of these

Table 10. ESTIMATES OF PARAMETERS IN THE SIMPLE LINEAR REGRESSION EQUATION OF $K_{obs}$ WITH ANALYZED SOILS VARIABLES

| Independent Variable Name | $X_i$ / $i$ | 46 Surface soils[a] | | | 7 Sub soils[a] | | |
|---|---|---|---|---|---|---|---|
| | | $\beta_o$[b] | $\beta_1$[b] | $r^2$[c] | $\beta_o$[b] | $\beta_1$[b] | $r^2$[c] |
| Knomo | 1 | .0020 | 1.0018 | .913 | -.1382 | 1.6698 | .430 |
| % clay | 2 | .3385 | .0009 | .003 | .7803 | -.0092 | .615 |
| % sand(old) | 3 | .4554 | -.0038 | .462 | .3561 | .0046 | .210 |
| % silt(old) | 4 | .0598 | .0057 | .669 | .2938 | .0034 | .042 |
| 2.0-1.0 mm sand | 5 | .3928 | -.0329 | .194 | .4004 | .0355 | .096 |
| 1.0-0.5 mm sand | 6 | .4144 | -.0174 | .409 | .3643 | .0282 | .180 |
| 0.5-0.25 mm sand | 7 | .4243 | -.0118 | .514 | .3643 | .0226 | .178 |
| 0.25-0.10 mm sand | 8 | .4181 | -.0068 | .272 | .3751 | .0117 | .162 |
| 0.10-0.05 mm sand | 9 | .4090 | -.0085 | .068 | .3040 | .0240 | .373 |
| % sand(new) | 10 | .4390 | -.0042 | .479 | .3731 | .0053 | .159 |
| % silt(new) | 11 | -.0226 | .0065 | .710 | -.1011 | .0114 | .320 |
| $M=X_{11}(X_{11}+X_{10})$ | 12 | -.0075 | .00008 | .736 | -.0596 | .00018 | .651 |
| Structure | 13 | .1546 | .0705 | .111 | e | e | e |
| Permeability | 14 | .0678 | .0770 | .407 | e | e | e |
| % C-total | 15 | .3872 | -.0288 | .008 | .6751 | -.3116 | .208 |
| % C-Na pyro. | 16 | .4072 | -.1712 | .012 | .5600 | -.8798 | .350 |
| % C-Hot $H_2O$ | 17 | .3998 | -.8726 | .028 | .3609 | 1.3245 | .092 |
| Periodate Consumed | 18 | .3654 | -.0397 | .001 | d | d | d |
| $Fe_2O_3$ | 19 | .2790 | .0504 | .037 | .4795 | -.0260 | .017 |
| $Al_2O_3$ | 20 | .1902 | .6677 | .124 | .1465 | 1.3668 | .185 |
| $SiO_2$ | 21 | .3727 | -.2301 | .005 | .6215 | -.9312 | .146 |
| ppm P | 22 | .3844 | -.00007 | .010 | .5380 | -.0001 | .049 |
| % N | 23 | .3182 | .3158 | .008 | .6470 | -5.4352 | .669 |
| % vermiculite | 24 | .3582 | -.0050 | .002 | .6154 | -.0600 | .291 |
| % mica | 25 | .3867 | -.0071 | .034 | .6690 | -.0222 | .339 |
| % kaolinite | 26 | .2775 | .0326 | .099 | .6552 | -.0563 | .269 |
| amor. material | 27 | .3156 | .1082 | .032 | .6135 | -.0435 | .158 |
| % montmorillonite | 28 | .3340 | .0083 | .014 | .5980 | -.0197 | .265 |
| % quartz | 29 | .3330 | .0121 | .003 | .6764 | -.0765 | .394 |
| % chlorite | 30 | .3331 | .0072 | .012 | .6239 | -.0428 | .839 |
| $X_{19}+X_{20}$ | 31 | .2677 | .0498 | .046 | .4734 | -.0201 | .011 |
| $(X_7)^2$ | 32 | .3880 | -.0004 | .429 | .4003 | .0016 | .087 |
| $(X_{31})\ (X_2)$ | 33 | d | d | d | .5976 | -.0023 | .307 |
| $(X_{31})\ (X_{28})$ | 34 | .3352 | .0043 | .014 | .6078 | -.0125 | .368 |
| $(X_{16})\ (X_2)$ | 35 | .3686 | -.0027 | .005 | .5538 | -.0174 | .600 |
| $(X_{16})\ (X_{28})$ | 36 | .3463 | .0102 | .003 | .5472 | -.0673 | .489 |
| Specific surface | 37 | .3266 | .0006 | .015 | .6667 | -.0019 | .349 |
| $X_5+X_7$ | 38 | .4302 | -.0107 | .528 | nd | nd | nd |
| $(X_{11})(X_{11})$ | 39 | .1269 | .00006 | .681 | nd | nd | nd |

[a] Kobs and Knomo for surface soil from Table 6 and for subsoils from Tab. 5.

[b] $K\ pred = \beta_o + \beta_1 X_i$

[c] Coefficient of determination or the square of the simple coefficient of correlation, r.

[d] Correlation insufficient for computation.

[e] Values of independent variables were constant.

was found to be any large benefit to the analysis.

## STATISTICAL ANALYSIS OF SURFACE SOIL DATA

Simple linear correlation analysis of the observed K, $K_{obs}$, values for the surface soils with each of the independent variables reported in Tables 7, 8 and 9 reveals that about half of the variables are positively correlated with $K_{obs}$ whereas the other one-half are negatively correlated (Table 10). The values used for all of the independent variables considered in Table 10, and for all subsequent statistical analysis reported later, have been converted to a whole soil base. That is, all of the values for the sand size fractions were converted to percent whole soil in lieu of percent of sand as reported in Table 7 and the clay mineralogical composition values were converted to percent whole soil in lieu of percent of the clay fraction as reported in Table 9. There are several combinations of variables calculated and reported in Table 10, such as the % Fe + Al as $X_{31}$ and the percent silt (new) squared as $X_{39}$. The combinations of variables that proved to be of significant help in the statistical analysis were those represented by $X_{12}$ and $X_{31}$. The specific surface variable, $X_{37}$, was an attempt to estimate the specific surface area of the soil from the amount of the various clay minerals present and the specific surface areas reported in the literature for the various clay minerals. The correlation matrix for the surface soil variables is reported in Table 16, Appendix C.

Multiple linear regression analysis was performed on the surface soil data with $K_{obs}$ as the dependent variable using the WRAP. The partial regression coefficients of the multiple linear regression equations are reported in Table 11. Table 11 contains the last 6 steps in the backward elimination of variables in an initial model containing 22 independent variables. The final model at step 6 contains 4 variables which are significant at the 0.05 probability level. The initial model considered in Table 11 contained all of the single variables analyzed (29) except for % sand-new ($X_{10}$), % silt-new ($X_{11}$) and the five sand fractions ($X_5$ - $X_9$, inclusive). Later analysis including the combination variable % Fe + % Al ($X_{31}$) did not alter the deletion process in

Table 11. ESTIMATES OF PARTIAL REGRESSION COEFFICIENTS IN THE MULTIPLE LINEAR REGRESSION EQUATION OF $K_{obs}$ WITH SURFACE SOIL VARIABLES[a]

| Independent Variable Name | $X_i$[b] | Partial regression coefficients in the multiple linear regression equation | | | | | |
|---|---|---|---|---|---|---|---|
| | | Step 1 | Step 2 | Step 3 | Step 4 | Step 5 | Step 6 |
| Constant | $X_o$ | -0.1344 | -0.1382 | -0.1287 | -0.1395 | -0.1357 | -0.1357 |
| M x $10^{-5}$ | $X_{12}$ | 6.3932 | 6.9180 | 6.7004 | 6.5201 | 6.6044 | 6.7097 |
| Permeability | $X_{14}$ | 0.03780 | 0.03291 | 0.03540 | 0.03639 | 0.03938 | 0.03847 |
| Structure | $X_{13}$ | 0.03704 | 0.04083 | 0.03624 | 0.03770 | 0.03532 | 0.03448 |
| % C-Na pyro. | $X_{16}$ | -0.3255 | -0.1879 | -0.1992 | -0.1673 | -0.1603 | -0.1732 |
| % mica | $X_{25}$ | -0.01779 | -0.01213 | -0.00366 | -0.00461 | -0.00109 | |
| % clay | $X_2$ | 0.01253 | 0.00949 | 0.00206 | 0.00177 | | |
| % chlorite | $X_{30}$ | -0.02060 | -0.01438 | -0.00366 | | | |
| % amor. mat. | $X_{27}$ | -0.03592 | -0.02857 | | | | |
| % N | $X_{23}$ | 0.5645 | | | | | |
| Coefficient of determination ($r^2$) | | 0.921 | 0.912 | 0.905 | 0.903 | 0.899 | 0.899 |

[a] Backward elimination of variables (WRAP) until all variables remaining are significant at the 0.05 probability level.

[b] As defined in Table 10.

the last six steps. Therefore, the model as proposed in step 6 would be the best model to use to predict K for surface soils. The model proposed in step 6 might best be written as:

$$K_{pred} = 0.1357 + (6.710)(10^{-5}) X_{12} + 0.03448X_{13} + 0.03847X_{14} - 0.1732X_{16}$$

where the $X_i$ are those reported in Table 10.

With the use of the SPSS regression program we arrive at the same conclusions as reported above. That is, with the forward selection of independent variables to be added to the regression model on the basis of highest partial correlation we arrive at the models reported in Table 12. The variables included in the models up to and including those of step 4 are statistically necessary, at the 0.05 probability level, to adequately predict the dependent variable, K. The slight differences in the partial regression coefficients in the models arrived at by the two methods when the same independent variables are included, such as step 6, Table 11 and step 4, Table 12, is attributed to numerical accuracy differences of the two programs.

It is very interesting to note that the four most significant variables to be included in the surface soil model to predict K are essentially the same four variables that Wischmeier, Johnson and Cross (1971) use in their nomograph to predict soil erodibility. The only difference being the use of sodium pyrophosphate extractable carbon in the former and percent organic matter in the latter. The sodium pyrophosphate extractable carbon is highly correlated with the percent organic matter, $r = 0.866$. It is thought by the authors that the sodium pyrophosphate extractable carbon is more representative of that organic material in soils which can affect intra-particle bonding in soils.

## STATISTICAL ANALYSIS OF SUBSOIL DATA

The main problem in establishing a model for the prediction of subsoil erodibility is the low number of $K_{obs}$ values from subsoils. The correlation matrix for the subsoil variables is reported in Table 17, Appendix C. With only 7 sets of observations for the subsoils, any

Table 12. ESTIMATES OF PARTIAL REGRESSION COEFFICIENTS IN THE MULTIPLE LINEAR REGRESSION EQUATION OF $K_{obs}$ WITH SURFACE SOIL VARIABLES[a]

| Variable | $X_i$[b] | Partial regression coefficients in the multiple linear regression equation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Step 1 | Step 2 | Step 3 | Step 4 | Step 5 | Step 6 | Step 7 | Step 8 | Step 9 |
| Constant | | -0.00753 | -0.1270 | -0.1894 | -0.1447 | -0.1503 | -0.2184 | -0.2226 | -0.2561 | -0.2613 |
| M x $10^{-5}$ | $X_{12}$ | 7.9616 | 6.7259 | 6.8147 | 6.8711 | 6.9787 | 7.5961 | 7.8378 | 7.8661 | 8.1960 |
| Permeability | $X_{14}$ | | 0.0472 | 0.0399 | 0.0376 | 0.0343 | 0.0367 | 0.0367 | 0.0405 | 0.0382 |
| Structure | $X_{13}$ | | | 0.0303 | 0.0338 | 0.0358 | 0.0337 | 0.0343 | 0.0297 | 0.0292 |
| % C-Na pyro. | $X_{16}$ | | | | -0.1571 | -0.1692 | -0.1232 | -0.1204 | -0.1850 | -0.2390 |
| % mont. | $X_{28}$ | | | | | 0.0048 | 0.0081 | 0.0095 | 0.0122 | 0.0118 |
| 0.25-0.1 mm sand | $X_8$ | | | | | | 0.0016 | 0.0027 | 0.0035 | 0.0040 |
| 0.1-0.05 mm sand | $X_9$ | | | | | | | -0.0037 | -0.0039 | -0.0043 |
| % N | $X_{23}$ | | | | | | | | 0.3377 | 0.4167 |
| % vermiculite | $X_{24}$ | | | | | | | | | 0.0085 |
| Coefficient of determination ($r^2$) | | 0.736 | 0.871 | 0.888 | 0.897 | 0.902 | 0.908 | 0.915 | 0.919 | 0.922 |

[a] Forward selection of variables on basis of highest partial correlation of the variables that are not subsequently in the model.

[b] As defined in Table 10.

model containing 6 independent variables will completely predict the dependent variable from the 7 observations. Therefore, weighted regression analysis was used in which each of the 46 surface soil observations were weighted 1/46 or 0.021739 and the 7 subsoil were weighted 1/7 or 0.142857.

The weighting and subsequent regression analysis was performed using the weighted regression analysis programs (WRAP). The partial regression coefficients and the coefficients of determination for this weighted model are reported in Table 13. It was hoped that by using this type of approach we could determine those basic independent variables that affect the prediction of K in both surface soil and subsoils.

Comparison of the variables necessary to predict K in the combined surface soil and subsoil weighted regression model of Table 13, with those in the model developed in Tables 11 and 12 for surface soils reveals that the amount of sodium citrate-bicarbonate-dithionite (CDB) extractable Fe and Al, $X_{31}$, and CDB extractable Si, $X_{21}$, might be important in the former model and are not even considered in the latter. Therefore, the amount of CDB extractable Fe, Al and Si must be important in predicting the K factor of subsoils. Such a model is shown in Table 14 along with some additional models. On the basis of F-test analysis the amount of sodium pyrophosphate extractable carbon is not statistically necessary, at the 5 percent level, to predict K for high clay subsoils. However, if the percent silicon released by CDB extraction is included with M and the % Fe + % Al there is a statistical improvement in the prediction model, Table 14-Equation 7, at the 5 percent level. Therefore, the model

$$K_{pred} = 0.32114 + 20.167X10^{-5}\ X_{12} - 0.14440X_{31} - 0.83686X_{21}$$

can be used to statistically predict the erodibility of the high clay subsoils considered in this study.

Table 13. ESTIMATES OF PARTIAL REGRESSION COEFFICIENTS IN THE WEIGHTED MULTIPLE LINEAR REGRESSION EQUATION OF $K_{obs}$ WITH SURFACE AND SUBSOIL VARIABLES[a]

| Independent Variable Name | $X_i$[b] | Partial regression coefficients in the multiple linear regression equation | | | | | |
|---|---|---|---|---|---|---|---|
| | | Step 1 | Step 2 | Step 3 | Step 4 | Step 5 | Step 6 |
| Constant | | -0.05513 | -0.13859 | -0.16775 | -0.24337 | -0.15458 | -0.00526 |
| % silt-old | $X_4$ | 0.00840 | 0.00903 | 0.00931 | 0.01007 | 0.01002 | 0.00889 |
| % C-Na pyro. | $X_{16}$ | -0.61251 | -0.58304 | -0.58278 | -0.57060 | -0.67752 | -0.72662 |
| % $Fe_2O_3$+%$Al_2O_3$ | $X_{31}$ | -0.10516 | -0.09887 | -0.09508 | -0.08272 | -0.09160 | -0.09438 |
| 0.1-0.05 mm sand | $X_9$ | 0.01290 | 0.01288 | 0.01401 | 0.01590 | 0.01441 | 0.01448 |
| Structure | $X_{13}$ | 0.06545 | 0.06494 | 0.06466 | 0.06278 | 0.08661 | 0.06929 |
| 1.0-0.5 mm sand | $X_6$ | 0.00442 | 0.00547 | 0.00676 | 0.00902 | 0.00724 | |
| Permeability | $X_{14}$ | 0.03096 | 0.03305 | 0.03175 | 0.02328 | | |
| % $SiO_2$ | $X_{21}$ | -0.29004 | -0.24154 | -0.31414 | | | |
| % montmorillonite | $X_{28}$ | -0.00424 | -0.00304 | | | | |
| 0.25-0.1 mm sand | $X_8$ | -0.00148 | | | | | |
| Coefficient of determination ($r^2$) | | 0.841 | 0.840 | 0.838 | 0.830 | 0.820 | 0.805 |

[a] Backward elimination of variables (WRAP) until all variables remaining are significant at the 0.05 probability level.

[b] As defined in Table 10.

Table 14. ESTIMATES OF PARTIAL REGRESSION COEFFICIENTS IN THE MULTIPLE LINEAR REGRESSION EQUATION OF $K_{obs}$ WITH SUBSOIL VARIABLES[a]

| Independent Variable Name | $X_i$[b] | Partial regression coefficients in the multiple linear regression equation | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Equation 1 | Equation 2 | Equation 3 | Equation 4 | Equation 5 | Equation 6 | Equation 7 |
| Constant | | 0.00367 | 0.17565 | -0.09575 | 0.05255 | 0.18608 | -0.07558 | 0.32114 |
| $M \times 10^{-5}$ | $X_{12}$ | 23.001 | 19.496 | 24.271 | 21.907 | 20.204 | 24.161 | 20.167 |
| % $Fe_2O_3$+% $Al_2O_3$ | $X_{31}$ | -0.10839 | -0.12085 | -0.10020 | -0.10550 | -0.12241 | -0.10562 | -0.14440 |
| % C-Na pyro. | $X_{16}$ | | -0.34917 | | | | | |
| % C-total | $X_{15}$ | | | 0.06213 | | | | |
| % clay | $X_2$ | | | | -0.00064 | | | |
| % montmorillonite | $X_{28}$ | | | | | -0.00929 | | |
| % amor. mat. | $X_{27}$ | | | | | | 0.01006 | |
| % $SiO_2$ | $X_{21}$ | | | | | | | -0.83686 |
| Coefficient of determination ($r^2$) | | 0.904 | 0.921 | 0.905 | 0.905 | 0.933 | 0.909 | 0.950 |

[a] The WRAP were used to obtain these values without using the backward elimination option.
[b] As defined in Table 10.

# VII. A NOMOGRAPH FOR ESTIMATING THE ERODIBILITY FACTOR, K, OF HIGH CLAY SUBSOILS

A nomograph which can be used to predict the erodibility factor, K, of subsoils is shown in Figure 55. The nomograph was developed from the multiple linear regression equation (Section VI) relating the erodibility factor to the soil texture factor, M, the amount of CDB extractable iron and aluminum oxides, and the amount of CDB extractable silica. The nomograph is similar to that developed for surface soils (Wischmeier et al., 1971). The equation used to derive the nomograph was:

$$K_{pred} = 0.32114 + 2.0167 \times 10^{-4} M - 0.14440 (\% Fe_2O_3 + \% Al_2O_3) - 0.83686 (\% SiO_2)$$

The soil texture factor, M, is calculated arithmetically by summing the percent "new" silt (2 - 100 μm mean diameter) and "new" sand (100 - 2000 μm mean diameter) then multiplying the sum by the percent "new" silt.

Inspection of the nomograph reveals that for given levels of CDB extractable iron plus aluminum oxide and silica, the erodibility factor, K, increases with an increase in M. The soil texture factor, M, is in turn influenced by the relative proportions of sand, silt and clay in the sample. In high clay soils, M is generally low and a function of the ratio of silt to sand. In sandy soils, M is also lower than in more silty soils and behaves as a function of the clay to silt ratio. The value of M increases as the square of the silt content when soils grade from loamy sands to sandy loams. The same trend is evident when soil textures grade from clays to silty clays to silty loams to silt loams and to silts.

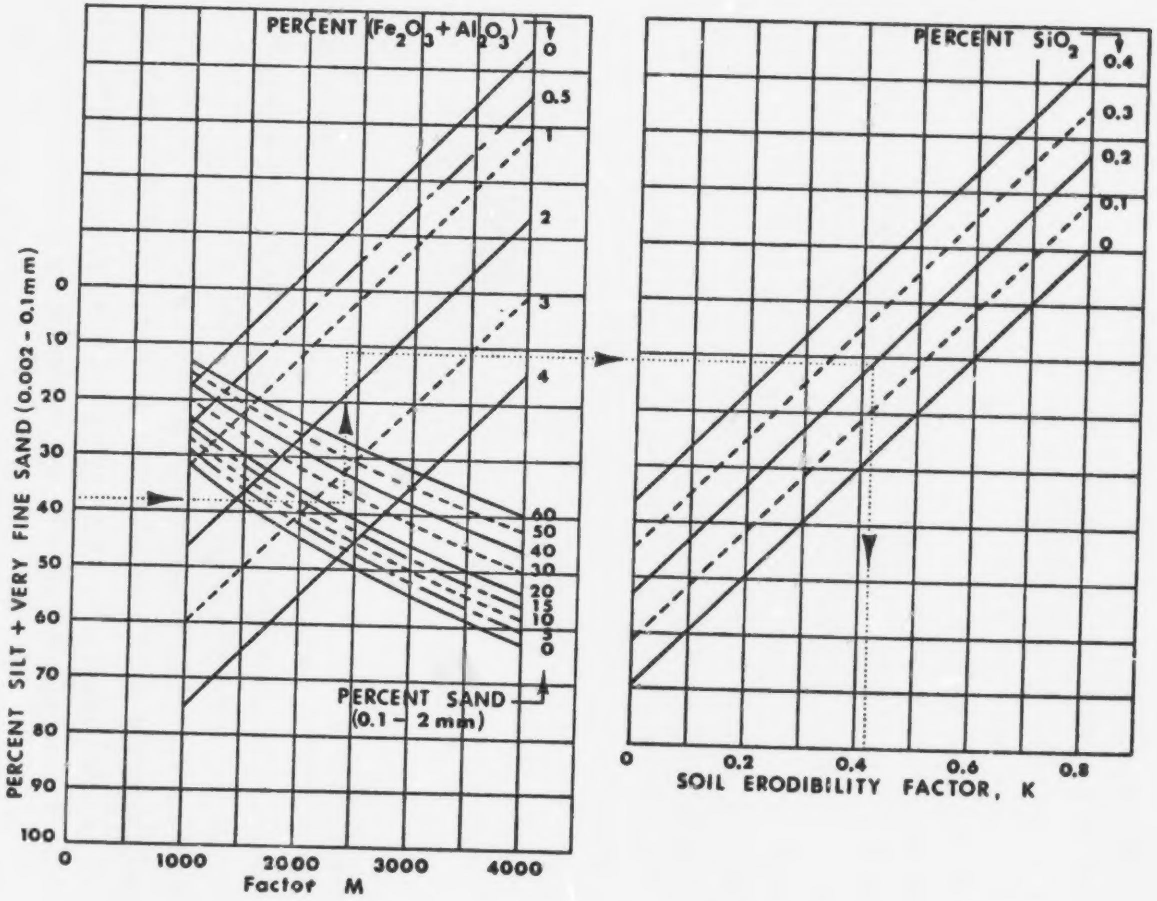


Figure 55. Nomograph for Estimating the Erodibility Factor, K, of High Clay Subsoils

It is also evident from the nomograph that at a given value of M there is a decrease in K with an increase in the amount of iron and aluminum oxides and silica in the sample. This finding is expected because amorphous iron and aluminum hydrous oxides and hydrous silica are known to bind soil particles into stable aggregates. Although the citrate-dithionite-bicarbonate (CDB) reagent used to extract these soils removes some of the crystalline iron oxides, it is most likely that almost all of the iron extracted by CDB from the subsoil samples used in this study was in the amorphous form. The CDB reagent will extract a very small amount of aluminum and silicon from crystalline clay minerals. However, the amounts of aluminum and silicon extracted from the subsoils used in this study, suggest that the Al and Si is combined with the amorphous iron oxide and is released when the iron is solubilized by the CDB reagent.

The chemistry of iron and aluminum suggest that their reactions with primary soil particles should be similar. This suggestion is supported by the observation that the summation of CDB extractable iron and aluminum oxides leads to a factor that serves as a better predictor of K than does iron and aluminum oxides when used separately in the model. The inclusion of CDB extractable silicon in this summation does not statistically improve the prediction of K; however, when silica is included as a separate term in the model along with $Fe_2O_3 + Al_2O_3$ there is a statistical improvement in the resulting regression model. This suggests that CDB extractable iron and aluminum act similarly in serving as binding agents in subsoils and that CDB extractable silica, important in predicting the erodibility of high clay subsoils, reacts differently with the primary soil particles than do iron and aluminum oxides. Evidently the amorphous iron and aluminum oxides and silica are the primary binding agents in subsoils, much as organic matter is the primary binding agent in surface soils, which promotes the formation of soil aggregates that are resistant to raindrop detachability.

The nomograph is used by entering the sum of new silt (2 - 100 μm diameter) on the left-most vertical axis and proceeding horizontally to intercept the curve for the appropriate sand content (100 - 2000 μm diameter). From this point proceed vertically to intercept the appropriate curve for the percent $Fe_2O_3$ + $Al_2O_3$. Then proceed horizontally to intercept the appropriate curve for the percent $SiO_2$ and from there proceed vertically to the bottom horizontal axis. At the point where the vertical line intersects the bottom right-hand horizontal axis the value predicted for K may be read directly. The value for M is not precomputed nor used directly, but rather may be calculated indirectly in using the nomograph by drawing a vertical line from the point of intersection of the "new" silt (2 - 100 μm diameter) horizontal with the appropriate curve for "new" sand (100 - 2000 μm diameter) to the bottom, left-hand, horizontal axis.

Table 15 gives a comparison of K values observed in field experiments with seven subsoils and similar values computed with the nomograph. A close relationship exists between the K values predicted by the nomograph and those measured in field experiments. The difference in K values between observed and predicted by the nomograph exceeds 0.03 only in the case of the St. Clair subsoil where the nomograph underestimates the observed K by 0.09.

The nomograph may be used with some degree of confidence with subsoils similar to those used in this study because the study soils represented a wide range in K values, textural composition, chemical composition, clay mineralogy and pedogenic origin. It should be emphasized that the nomograph may not be applicable to subsoils having large amounts of iron and aluminum in crystalline forms which are extractable by the CDB reagent. The iron and aluminum in such subsoils may not be active in binding soil particles into aggregates which resist raindrop disruption. The nomograph would therefore underestimate the K for subsoils containing large amounts of crystalline iron and aluminum compounds since the nomograph is based on the finding that CDB extractable iron, aluminum and silicon content of soils is inversely related to the soil erodibility factor. The nomograph may not be applicable to subsoils that have a structure other than blocky or massive and a permeability other than very slow. It would be necessary to investigate

## Table 15. COMPARISON OF THE SOIL ERODIBILITY FACTOR, K, DETERMINED IN FIELD EXPERIMENTS AND THOSE COMPUTED FROM THE SUBSOIL NOMOGRAPH

| Soil | Sample ID number | Soil erodibility factor, K | |
|---|---|---|---|
| | | Observed | nomograph[a] |
| Dayton | 188 | .54 | .57 |
| McGary | 191S | .36 | .39 |
| Portageville | 192S | .05 | .08 |
| St. Clair | 212S | .48 | .39 |
| Pawnee | 206S | .45 | .42 |
| Mayberry | 208S | .67 | .69 |
| Wymore | 210S | .49 | .49 |

[a] Soil erodibility factor, K, as determined from Figure 55.

subsoils that have other structures and permeabilities to determine the exact effect of these two variables on the erodibility of subsoils.

The use of this nomograph to predict erosion at a proposed construction site should include the following steps:

1. Composite subsoil samples should be collected which represent each subsoil horizon and/or topographical characteristic proposed for prolonged exposure during the construction phase.
2. These subsoil samples should be submitted to a soil characterization laboratory for particle size analysis (silt, 2 - 100 μm and sand, 100 - 2000 μm) and determination of iron, aluminum and silicon released by citrate-dithionite-bicarbonate (CDB) extraction. The particle size analysis can be performed on the same sample used for the CDB extraction following the procedure of Jackson, 1956.
3. The results from these analyses can then be used to predict the soil erodibility factor, K, for each of the areas involved by using the nomograph presented in Section VII of this report.
4. Soil loss values can then be estimated using the Universal Soil-Loss Equation using procedures outlined by Wischmeier and Smith, 1965.

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# IX. APPENDICES

Page

A. Profile Descriptions of Soils Used in This Study . . . . . 83

B. Methods Modified or Developed and Used During the Course of This Study . . . . . . . . . . . . . . . . . . . . 97

C. Correlation Matrix of Surface Soil and Subsoil Variables . . . . . . . . . . . . . . . . . . . . . . . . 105

# APPENDIX A

# PROFILE DESCRIPTIONS OF SOILS USED IN THIS STUDY

Soil type: McGary silt loam

Location: 3.9 mi. north of Bloomington, Indiana, along highway 37, approximately 150 feet west (TW 9, N R 1, W sect. S4, NW 1/4)

Land Use: pasture

Parent Material: calcareous lacustrine

Physiography: lake bed

Slope: 2%

Salt or Alkali: none

Stoniness: none

Erosion: none

Aspect: south

Root Distrib.: none

Permeability: slow to very slow

Drainage: somewhat poorly

Ground water: deep

Profile description:[a]

Ap -- 0-11" -- Gray (10YR 5/1-6/1) silt loam; fine cloddy somewhat compact and massive; friable; neutral; abrupt smooth boundary. (6 to 11 inches thick.)

B21gt -- 11-15" -- Grayish-brown (10YR 5/2) light silty clay, common, fine, faint gray (10YR 6/1) mottles; moderate medium subangular blocky structure; firm; medium acid; clear smooth boundary. (2 to 5 inches thick.)

B22gt -- 15-22" -- Grayish-brown (10YR 5/2) silty clay, common fine faint yellowish-brown (10YR 5/2) mottles; weak, fine soft black (10YR 2/1) manganese and iron oxide concretions; thin gray (10YR 5/1) clay films on ped faces; firm; neutral; clear smooth boundary. (5 to 10 inches thick.)

B23gt -- 22-27" -- Grayish-brown (10YR 5/2) silty clay, common fine faint yellowish-brown (10YR 5/4) mottles; moderate medium prismatic structure, breaking to moderate to strong medium angular blocky structure; thin gray (10YR 5/1) clay films on ped faces; tongues

---

[a] Profile description taken from Soil Survey.

McGary silt loam (cont'd.)

of gray (10YR 5/1) silty clay, 1 to 2 inches thick and 6 to 10 inches apart, firm; mildly alkaline; gradual irregular boundary. (4 to 10 inches thick.)

B3gt -- 27-39" -- Gray (10YR 5/1) light silty clay, common fine distinct light yellowish-brown (10YR 6/4) mottles; moderate to strong, fine to medium prismatic structure, breaking to moderate to strong, medium blocky structure; firm; mildly alkaline; clear irregular boundary. (9 to 15 inches thick.)

Cg -- 39-50" -- Gray (10YR 6/1) stratified silty clay loam and clay, common fine distinct yellowish-brown (10YR 5/6) mottles; moderate coarse blocky structure; firm; thin gray (10YR 5/1) clay films on ped faces; calcareous; tongues of the B3 horizon project into this horizon.

Soil type: Portageville clay

Location: Delta Experiment Station, Portageville, Mo.

Land Use: Cultivated

Parent Material: alluvial deposit

Physiography: backwater deposit

Slope: 0%

| | |
|---|---|
| Salt or Alkali: none | Permeability: very slow |
| Stoniness: none | Drainage: poor |
| Erosion: none | Ground Water: shallow |

Aspect: none

Root distrib.: none

Profile description:[a]

Ap -- 0- 6" -- Very dark grayish brown (10YR 3/2) clay with few, fine, dark reddish-brown (5YR 3/3) mottles; weak, fine to medium, granular structure; very firm; pH 7.0; abrupt, smooth boundary.

A1 -- 6-15" -- Very dark gray (10YR 3/1) clay with common, medium, dark reddish-brown (5YR 3/4) mottles; moderate, fine to medium, subangular blocky structure; very firm; few fine roots and pores; Ph 7.5, weakly calcareous; gradual, smooth boundary.

B1 -- 15-25" -- Dark-gray (5Y 4/1) clay with common, medium, dark reddish-brown (5YR 4/3) mottles and few, coarse, yellowish-red (5YR 4/6) mottles; moderate, medium, angular blocky structure; very firm; few polished surfaces 1 to 4 inches across in angular position (slickensides); pH 8.0, weakly calcareous; gradual, smooth boundary.

B2 -- 25-47" -- Gray (5Y 5/1) clay with few, fine, dark reddish-brown (2.5YR 2/4) mottles and common, fine, dark reddish-brown (5YR 3/4) and yellowish-red (5YR 4/8) mottles; weak, medium, angular blocky structure; very firm;

---

[a] Profile description taken from Soil Survey, Pemiscot County, Missouri, USDA-SCS, 1971.

Portageville clay, Po (cont'd.)

many ped interiors of dark grayish brown (2.5Y 4/2); few polished surfaces 1 to 4 inches across in angular position (slickensides); pH 8.0, strongly calcareous; gradual boundary.

C -- 47-60" -- Dark gray (5Y 5/1) and dark grayish-brown (10YR 4/2) clay with common, fine, dark reddish-brown (5YR 3/4) and dark-brown (7.5YR 4/4) mottles; massive, stratified; strata are 1/2 inch to 2 inches thick; dark reddish-brown (5YR 3/4) and yellowish-red (5YR 4/8) colors appear as thin lines between the strata, and there are occasional thin lenses (about 1/2 inch thick) of very fine sandy loam; very firm; pH 8.0, strongly calcareous.

At a depth between 10 and 40 inches, these soils have a clay content of 40 to 65 percent or more.

The A horizon ranges mainly from 10 to 20 inches in thickness, but is as much as 24 inches in places. Color ranges from 10 YR to 2.5Y in hue, 2 to 3 in value, and 0 to 2 in chroma. The texture is commonly clay and silty clay loam, but there are areas of sandy loam or loamy sand overwash.

The B1 horizon ranges from 10YR to yellower in hue, has a value of 3.5 to 4.5, and has a chroma of 1. The B2 and C horizons range from 10YR to yellower in hue and have a value of 4 to 6 and a chroma of 1. Ped interiors have a chroma of 1 or 2.

Reaction ranges from slightly acid to moderately alkaline in the top 10 inches, and from neutral to moderately alkaline below. The soil materialin the top 10 inches is calcareous in some places, and it ranges to violently calcareous below a depth of 10 inches.

NOTES: This soil occupies level and depressional areas on lakebeds and meanders of former channels in the recent Mississippi River

Portageville clay, Po (cont'd.)

flood plain. These areas are like oxbows in shape, are several hundred acres in size, and are in the eastern part of the county.

Classification: fine, montmorillonitic, calcareous thermic, vertic, haplapuoll

Soil type: Mayberry clay loam, F2G2D

Location: .16 mi. E and 350' N from SW corner, Sec. 35, T 7 N, R 10 E Otoe County

Land use: cultivated

Parent material: stratified clay loam, sandy loam and clay (Fullerton formation?)

Physiography: upland

Slope: 18%

Salt or Alkali: none

Stoniness: none

Erosion: moderate

Slope: north

Root distrib.: none

Permeability: slow

Drainage: moderately well

Ground water: very deep

Profile description:[e]

| | |
|---|---|
| Alp -- 0- 8" --<br>S72Neb-66-1-1 | Dark brown (7.5YR 3/2) moist; clay loam; weak coarse blocky parting to weak coarse to fine granular structure; hard, friable; medium acid (pH 5.6); clear smooth boundary. |
| [a]B21t -- 8-20" --<br>S72Neb-66-1-2 | 50% dark brown (7.5YR 3/2) and 50% reddish-brown (5YR 4/4) moist; clay; weak coarse blocky parting to strong medium and fine angular blocky structure; extremely hard, very firm; slightly acid (pH 6.5); gradual smooth boundary. |
| [b]B22t --20-40" --<br>S72Neb-66-1-3 | Brown (10YR 5/3) moist; silty clay to clay; moderate medium angular blocky structure; extremely hard, very firm; neutral (pH 7.0); gradual smooth boundary. |
| [c]B23t --40-53" --<br>S72Neb-66-1-4 | Dark brown (7.5YR 4/4) moist; clay; moderate medium and coarse angular blocky structure; extremely hard, very firm; clear smooth boundary. |
| [d]C --53-65" --<br>S72Neb-66-1-5 | Yellowish brown (10YR 5/4) moist; stratified clay loam and sandy loam; weak coarse blocky structure; hard, friable. |

Mayberry clay loam, F2G2D (cont'd.)

NOTES: This soil thought to be formed in Paleosol or clayey sediments of Fullerton formation. 100' of crest has reddish brown color, heavy clay loam or silty clay loam in upper 2'. Moved downslope for erosion study because of slope and testure. This profile possibly taxadjunct because of brown color and is part of Mayberry mapping unit. Thick clay films in lower B and C could be characteristic of the parent material, as this has been observed elsewhere.

Classification: fine, montmorillonitic, mesic family of Aquic Argiudolls.

---

[a] Few dark organic coatings, common, small, hard, round dark accumulations, thin patchy clay film.

[b] Few large dark organic coatings along cracks, few faint dark accumulations, common distinct brown mottles (7.5YR 4/4) thin patchy clay films.

[c] Common soft, diffuse dark accumulations, thick discontinuous dark brown clay films fill pores and channels, few hard lime concretions, few gravel.

[d] Many thick dark brown clay films fill channels.

[e] Courtesy of Mr. H. Sauter, District Soil Scientist, USDA-SCS, Otoe County, Syracuse, Nebraska.

Soil type: Pawnee clay loam, F2GD

Location: .5 mi. N, .3 mi. W and 580' S from SE corner, Sec. 27-7-9
Otoe County

Land use: cultivated

Parent material: calcareous glacial drift

Physiography: upland

Slope: 8%

Salt or Alkali: none

Stoniness: none

Erosion: moderate

Aspect: east

Root distrib.: none

Permeability: slow

Drainage: moderately well

Ground water: very deep

Profile description:[e]

| | |
|---|---|
| Alp -- 0- 7" --<br>S72Neb-66-2-1 | Very dark brown (10YR 2/2) moist; clay loam, weak coarse blocky parting to weak coarse to fine grandular structure; hard, friable; slightly acid (pH 6.4); clear smooth boundary. |
| [a]B21t -- 7-18" --<br>S72Neb-66-2-2 | Very dark grayish-brown (10YR 3/2) moist; clay; moderate, medium angular blocky structure; extremely hard, very firm; neutral (pH 6.8); gradual smooth boundary. |
| [b]B22t --18-25" --<br>S72Neb-66-2-3 | Dark brown (10YR 4/3) moist; clay; moderate coarse and medium angular blocky structure; extremely hard, very firm; neutral (pH 7.2); gradual smooth boundary. |
| [c]B23t --25-40" --<br>S72Neb-66-2-4 | Grayish-brown (10YR 5/2) moist; clay; moderate coarse and medium angular blocky structure; extremely hard; very firm; gradual smooth boundary. |
| [d]B3 --40-60" --<br>S72Neb-66-2-5 | Grayish-brown (2.5Y 5/2) moist; heavy clay loam; moderate medium angular blocky structure; very hard; firm. |

Pawnee clay loam, F2Gd (cont'd.)

NOTES: This is moderately eroded soil (about 50 x 50') included in mapping unit, Pawnee soils, severely eroded. (Slope in this general area of mapping unit averages about 7%.)

Classification: fine, montmorillonitic, mesic family of Aquic Arguidolls.

---

[a] Few brown (7.5YR 4/4) mottles, thin discontinuous clay films.

[b] Few brown (7.5YR 4/4) mottles, many very dark brown (10YR 2/2) organic coatings along cracks, thin discontinuous clay films.

[c] Common yellowish brown (10YR 5/4) mottles, common organic coatings, common hard lime concretions, thin discontinuous clay films.

[d] Many prominent dark accumulations (manganese), few brown accumulations (iron), few soft lime concretions, thin patchy clay films.

[e] Courtesy of Mr. H. Sauter, District Soil Scientist USDA-SCS, Otoe County, Syracuse, Nebraska.

Soil type: Wymore silty clay loam, F2DC

Location: .5 mi. N, .45 mi. W and 130' S from SE corner, Sec. 27,
T 7 N, R 9 E, Otoe County

Land use: cultivated

Parent material: silty clay loam, loess

Physiography: upland

Relief: 5 1/2%

Salt or Alkali: none

Stoniness: none

Erosion: moderate

Aspect: east

Root Distrib.: none

Permeability: slow

Drainage: moderately well

Ground water: very deep

Profile description:[e]

| | |
|---|---|
| A1p -- 0- 8" --<br>S72Neb-66-3-1 | Very dark brown (10YR 2/2) moist; silty clay loam; weak coarse blocky parting to weak coarse to fine granular structure; hard, friable; slightly acid (pH 6.1); clear smooth boundary. |
| [a]B21t -- 8-19"--<br>S72Neb-66-3-2 | Mixed very dark brown (10YR 2/2), dark grayish-brown (10YR 4/2), and very dark grayish-brown (10YR 3/2) crushed, moist; silty clay; strong medium and fine angular blocky structure; extremely hard, very firm; neutral (pH 6.6); gradual smooth boundary. |
| [b]B22t --19-35" --<br>S72Neb-66-3-3 | Dark grayish-brown (2.5Y 4/2) moist; silty clay; strong medium and fine angular blocky structure; extremely hard; very firm; neutral (pH 7.0); gradual smooth boundary. |
| [c]B3t --35-48" --<br>S72Neb-66-3-4 | Mixed grayish-brown (2.5Y 4/2) and grayish-brown (2.5Y 5/2) moist; heavy silty clay loam; moderate medium angular blocky structure; very hard, firm; gradual smooth boundary. |

Wymore silty clay loam, (cont'd.)

[d]C --48-60" -- Grayish-brown (2.5Y 5/2) moist; silty clay loam;
S72Nev-66-3-5 weak coarse and medium blocky structure; hard, friable.

Classification: fine montmorillonitic, mesic family of Aquic Argiudolls.

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[a] Thin patchy clay films.

[b] Few faint small brown (7.5YR 4/4) mottles, common organic coatings, thin discontinuous clay films.

[c] Many prominent large brown (7.5YR 4/4) mottles, few pinhead-size dark accumulations, many small pores, common lime concretions, patchy clay films.

[d] Many prominent diffuse strong brown (7.5YR 5/6) mottles, many large and small pores.

[e] Courtesy of Mr. H. Sauter, District Soil Scientist USDA-SCS, Otoe County, Syracuse, Nebraska.

Soil type: St. Clair silty clay loam

Location: S13, T 31 N, R 14 E, Allen County, Indiana

Land use: cultivated

Parent material: calcareous till

Physiography: upland

Slope: 16%

Salt or Alkali: none

Stoniness: none

Erosion: moderate

Aspect: east

Root Distrib.: none

Permeability: slow to very slow

Drainage: moderately well

Ground water: deep

Profile description:[a]

Ap -- 0- 5" -- Dark grayish-brown (10YR 4/2) silt loam; weak, fine, granular structure; friable when moist; neutral; abrupt, smooth boundary.

B1 -- 5- 7" -- Brown (10YR 5/3) light silty clay loam; moderate, fine, subangular blocky structure; firm when moist; medium acid; clear, wavy boundary.

B21t -- 7-14" -- Brown (10YR 5/3) silty clay; weak, medium, prismatic structure breaking to strong, medium, angular blocky structure; very firm when moist; thin clay films on many ped faces; very strongly acid; clear, wavy boundary.

B22t -- 14-24" -- Brown (10YR 5/3) clay; few, fine, faint mottles of yellowish brown (10YR 5/8) in the upper part and common, medium, distinct mottles of yellowish brown in the lower part; weak, medium, prismatic structure; extremely firm when moist; thin to thick clay films on many ped faces; strongly acid; clear, wavy boundary.

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[a] Profile description taken from Soil Survey, Allen County, Indiana, USDA-SCS, 1969.

St. Clair silty clay loam (cont'd.)

C -- 24-40" -- Dark grayish-brown (10YR 4/2) heavy silty clay loam to silty clay; common, medium, prominent mottles of light gray (10YR 7/2); weak, medium, angular blocky structure; very firm when moist; calcareous.

The A horizon ranges from 5 to 10 inches in thickness and from silt loam to silty clay loam in texture. Soil material from the B1 horizon is mixed with that of the A horizon in many cultivated areas. In some places there is no B1 horizon. The depth to calcareous material ranges from 18 to 28 inches.

Classification: fine, illitic, mesic, typic hapludalf

# APPENDIX B

## METHODS MODIFIED OR DEVELOPED AND USED DURING THE COURSE OF THIS STUDY

## SODIUM CITRATE - SODIUM BICARBONATE - SODIUM DITHIONITE EXTRACTION OF SOILS

Free iron oxides are extracted from soils by a two step procedure in which organic matter is first removed with hydrogen peroxide and iron oxides are extracted with the CDB reagent.

A. Removal of organic matter with hydrogen peroxide

1. Add 10 ml increments of 30% $H_2O_2$ to a 5 g soil sample in a 600-ml beaker and digest until organic matter is destroyed. Evaporate the sample to a thin paste.
2. Transfer the sample to a 100-ml centrifuge tube using 0.5 N NaOAc (pH5).
3. Wash twice with 50 ml portions of .5 N NaOAc (pH 5), centrifuge at 2000 rpm, and decant.
4. Wash once with 0.5 N NaOAc (pH 7), centrifuge at 2000 rpm and decant.
5. Wash once with 0.5 N NaCl, centrifuge and decant.

B. Removal of iron oxides

1. Add 40 ml of sodium citrate-bicarbonate solution to each tube.
2. Heat the suspension in the tube to 75 - 80° C in a water bath. (Do not exceed 80° C or ferrous sulfide will form. Suspension should be a light gray. Black indicates ferrous sulfide.)
3. Add approximately 1 g of solid sodium dithonite ($Na_2S_2O_4$) to each tube. Stir constantly for 1 minute and allow to react for 5 minutes. Keep the temperature between 75 - 80° C.
4. After 5 minutes add an additional gram of sodium dithionite, stir and allow to react for five minutes.
5. Repeat step 4 once more.
6. Centrifuge at 1600 - 2000 rpm for 5 minutes and decant. IMPORTANT. Place supernatant liquid in a 250-ml volumetric flask and save for iron determination.

7. Wash twice with 0.5 N NaCl, centrifuge and decant the liquid into the 250-ml volumetric flask.
8. Wash once with 30 ml of water, centrifuge and decant liquid into volumetric flask.

### C. Determination of Fe in $Na_2S_2O_4$-Na Citrate-$NaHCO_3$ extract

1. Place appropriate aliquot of an air-oxidized sample (containing less than 400 mg of Fe) in a 100-ml volumetric flask.
2. Add 2 ml 10% $NH_2OH$-HCl (hydroxylamine hydrochloride).
3. Add 5 ml of NaOAc-HCl buffer.
4. Dilute to about 80 ml and mix.
5. Add 3 ml of 0.4% orthophenanthroline in 95% ethanol and mix well (There must be at least 8 mg of orthophenanthroline present in the final color development flask).
6. Dilute to volume with water.
7. Read at 510 mμ after 10 min. Color is stable at least 20 hours.

NaOAc-HCl buffer

81.6 g NaOAc
369 ml glacial HOAc
41.8 ml conc. HCl
Make to 1 liter with water

### D. Determination of low concentrations of Al in $Na_2S_2O_4$-Na citrate-$NaHCO_3$ extracts

1. Place an appropriate aliquot of air-oxidized extract containing 2-40 μg Al in a 50 ml beaker.
2. Add 10 ml concentrated $HNO_3$.
3. Add 3 ml concentrated $H_2SO_4$.
4. Mix.
5. Heat to dryness on hot plate then ignite at 400°C for 3 hours.
6. When cool add 1 ml 6NHCl and 20 ml water.
7. Digest on steam plate 30 min. then allow to cool.

8. Neutralize to pH 4.0 with 1$\underline{N}$ NaOH (determine with pH meter).
9. Add 2 ml 1% thioglycolic acid.
10. Digest 30 min. on steam plate.
11. Cool and add 10 ml aluminon-acetate buffer, transfer to 50 ml volumetric flask.
12. Allow to stand 1 hour and read at 530 mμ

Aluminon-acetate buffer

120 ml glacial HOAc - 900 ml $H_2O$
24 g NaOH
Mix
0.35 g aluminon
Dilute to 1 liter with water

## E. Determination of Si in Dithionite-Citrate-Bicarbonate Extracts*

1. Place 5 to 10 ml of an air-oxidized extract (containing 5 to 25 g Si) in a 50 ml volumetric flask.
2. Add 10 ml of 1 $\underline{N}$ $H_2SO_4$ and mix.
3. Add 10 ml of 0.3 $\underline{M}$ $MoO_4^{-2}$ and mix.
4. After 2 min. add 5 ml of 20% tartaric acid.
5. Add 1 ml of 1-amino-2naphthol-4-sulfonic acid reductant reagent.
6. Dilute to volume with distilled water.
7. Measure absorbance at 820 mμ after 30 min.

1 $\underline{N}$ $H_2SO_4$

Dilute 29 ml concentrated $H_2SO_4$ to 1 liter.

0.3 M molybdate

Dissolve 54.0 g of ammonium molybdate, $(NH_4)_6MoO_7O_{24} \cdot 4\ H_2O$ in approximately 800 ml of $H_2O$, adjust to pH 7.0 with 5 $\underline{N}$ NaOH and make to 1 liter volume.

20% tartaric acid

Dissolve 100 g of tartaric acid in 500 ml of $H_2O$.

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*The citrate dithionite extract, diluted to 500 ml, is assumed to contain 12 mmoles of Na citrate, 5 mmoles of $NaHCO_3$ and 17.5 mmoles of oxidized Na dithionite.

1-amino-2-naphthol-4-sulfonic acid reductant

Dissolve 25 g of $NaHSO_3$ in 200 ml of $H_2O$. Dissolve 2 g of anhydrous $Na_2SO_3$ and 0.4 g of 1-amino-2-naphthol-4-sulfonic acid in 25 ml $H_2O$. Combine the two solutions, dilute to 250 ml and store in a refrigerator in plastic.

F. Determination of hot water extractable carbon in soils

1. Add 10 g of <2 mm soil to 125 ml 24/40 Standard Taper Erlenmeyer flask.
2. Add 20 ml distilled water.
3. Boil under reflux for 30 min.
4. Rinse down condensor with small amount of $H_2O$.
5. Transfer contents of Erlenmeyer flask to centrifuge tube (50 ml) with small amount of $H_2O$.
6. Centrifuge at approximately 10,000 rpm for 10 min.
7. Decant supernatant into 50 ml volumetric flask.
8. Wash residue with 10 ml of hot water.
9. Centrifuge as before, decant and add washing to 50 ml volumetric flask.
10. Make to 50 ml final volume.
11. Take 5 ml aliquot for carbon determination add to 125 ml Standard Taper Erlenmeyer flask.
12. Add 5 ml of 0.2 N $K_2Cr_2O_7$ solution.
13. Add 15 ml concentrated $H_2SO_4$.
14. Boil under reflux for 30 min.
15. Remove from heat and cool sample.
16. Titrate sample with approximately 0.05 N ferrous ammonium sulfate solution using N-phenylanthanilic acid as an indicator.
17. Have boiled and unboiled blanks using 5 ml distilled $H_2O$ + 5 ml 0.5 N $K_2Cr_2O_7$ + 15 ml $H_2SO_4$.
18. Calculate data as described by Mebius (1960).

G. Determination of sodium pyrophosphate extractable carbon in soils

1. Weigh 5 g samples of < 2 mm soil into 50 ml centrifuge tubes.

2. Add exactly 25 ml of 0.15 M sodium pyrophosphate adjusted to pH 8.0.
3. Stopper tube and shake overnight approximately 16 hours.
4. Remove stoppers and centrifuge at 10,000 rpm for 10 minutes.
5. Decant supernatant.
6. Remove 5 ml aliquots of supernatant and place into 125 ml Standard Taper Erlenmeyer flasks.
7. Add 5 ml of 0.5 N $K_2Cr_2O_7$ + 15 ml concentrated $H_2SO_4$.
8. Boil under reflux for 30 min.
9. Remove from heat and cool sample.
10. Titrate sample with 0.1 N Ferrous ammonium sulfate solution using N-phenylanthranillic acid as redox indicator.
11. Have boiled and unboiled blanks using 5 ml distilled $H_2O$ plus 5 ml 0.5 N $K_2Cr_2O_7$ plus 15 ml concentrated $H_2SO_4$.
12. Calculate results as described by Mebius (1960).

### H. Periodate oxidizable polysaccharides in soil

Reagents:

1. 0.05 M (0.1 N) sodium periodate - Dissolve 10.695 g of $NaIO_4$ in distilled $H_2O$ and dilute to 1 liter.
2. 0.1 M (0.2 N) sodium arsenite - Dissolve 12.990 g of $NaAsO_2$ and 4 g of $NaHCO_3$ in water and dilute to 1 liter.
3. 0.05 M ().05 N) iodine solution - Dissolve 20 g of iodate-free KI in 40 ml of water. Add 6.35 g of sublimed iodine to the KI solution, stopper, shake and bring to 1 liter after iodine dissolves.
4. Starch solution - Make a paste of 1 g of soluble starch and a small amount of water. Pour the paste into 100 ml of boiling water and boil for 1 minute. Allow the solution to cool and add 3 g of KI. Use two ml aliquots for solution for titration.

Procedure:

Weigh out 2.5 g soil samples and place into small plastic bottles or 50 ml Erlenmeyer flasks. Add exactly 25 ml of 0.05 M periodate solution and place on a wrist action shaker for 24 hours (use very show speed). Centrifuge sample and place a 15 ml aliquot of supernatant into a 125 ml Erlenmeyer flask. Add 1 g of $NaHCO_3$ and 10 ml of 0.1 M $NaAsO_2$ solution. Wash down sides of flask and add 2 ml of starch solution. Titrate the mixture with 0.05 M iodine solution. Standardize the iodine solution by titration against 10 ml of arsenite solution (titration about 40 ml) and standardize periodate solution by adding 10 ml of arsenite solution to 15 ml of periodate and titrating the resultant mixture with iodine to starch end point. Always use a blank having 25 ml of periodate with your sample set and take 15 aliquot of this blank for subsequent titration.

Report results as millimoles of periodate consumed per gram of soil.

I. Procedure for the determination of mica in soil clays

1. A 100 mg clay sample that has been freshly treated with NaOAc buffer pH 5, $H_2O_2$ and NaOAc pH 7 is placed in a 15-ml centrifuge tube.
2. Wash five times with 1 M $(NH_4)_2\ CO_3$.
3. Transfer to a tared platinum crucible with water and dry overnight at 110° C.
4. Weigh crucibles after cooling 5 minutes in desiccator.
5. To the sample add several drops of water, .5 ml 60% perchloric acid and 5-10 ml bydrofluoric acid.
6. Cover 9/10 of crucible with platinum lid and place on 200-240°C sand bath and evaporate to dryness.
7. Repeat steps 5 and 6.
8. Remove and cool crucible.
9. Add 5 ml of 6 N HCl to the crucible and place on a porcelain plate and return to the 240° C hot plate for 1/2 hour.
10. Remove and cool for 10 minutes.
11. Transfer contents of crucible to 100-ml volumetric flask and dilute to volume with distilled water.

12. Determine K with flame photometer.

13. % mica = % $K_2O$ x 10.

J. Determination of quartz plus feldspar content of soil clays

1. Weigh 0.200 g of dried clay sample into a 50-ml vitreous silica crucible containing about 5 g $NaHSO_4$ (fused).
2. Mix sample with salt then add 7-10 g of $NaHSO_4$ (fused).
3. Fuse under hood.
4. Transfer cake to 150-ml beaker with 3 N HCl (approximately 60 ml) boil gently then transfer suspension to centrifuge tubes. Centrifuge and discard solution.
5. Wash 2 times with 3 N HCl.
6. Transfer residue from tube with 0.5 N NaOH to Ni-beaker. Make up to 100 - 150 ml of 0.5 N NaOH.
7. Bring suspension rapidly to boiling, boil for 25 minutes and cool in ice bath.
8. Transfer to plastic centrifuge tubes with 3 N HCl and centrifuge.
9. Transfer residue to weighed 18-ml centrifuge tubes.
10. Wash 3 times with 3 N HCl.
11. Dry at 110° C and weigh. Residue is amount of quartz plus feldspar in the sample.

# APPENDIX C

## CORRELATION MATRIX OF SURFACE SOIL AND SUBSOIL VARIABLES

## Table 16. CORRELATION MATRIX OF SURFACE SOIL VARIABLES (coefficient of correlation - r)

| $x_i$<br>i | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | $x_8$ | $x_9$ |
|---|---|---|---|---|---|---|---|---|
| 2 | 1.0000 | -.6184 | .2684 | -.2998 | -.4893 | -.5713 | -.5901 | -.2701 |
| 3 | | 1.0000 | -.9214 | .5187 | .7836 | .9162 | .9085 | .5452 |
| 4 | | | 1.0000 | -.4994 | -.7253 | -.8421 | -.8200 | -.5317 |
| 5 | | | | 1.0000 | .7851 | .4693 | .2565 | .0602 |
| 6 | | | | | 1.0000 | .8265 | .4904 | .1402 |
| 7 | | | | | | 1.0000 | .7501 | .2599 |
| 8 | | | | | | | 1.0000 | .5803 |

| | $x_{10}$ | $x_{11}$ | $x_{12}$ | $x_{13}$ | $x_{14}$ | $x_{15}$ | $x_{16}$ | $x_{17}$ |
|---|---|---|---|---|---|---|---|---|
| 2 | -.6232 | .2331 | -.0843 | .1999 | .3375 | .5205 | .2249 | .4995 |
| 3 | .9876 | -.8901 | -.7035 | -.1635 | -.4647 | -.3174 | -.1698 | -.1256 |
| 4 | -.9045 | .9800 | .9081 | .1054 | .4214 | .1208 | .0886 | -.0795 |
| 5 | .5540 | -.5377 | -.4417 | -.1226 | -.2484 | -.0012 | .1502 | .0639 |
| 6 | .8276 | -.7684 | -.6327 | -.2258 | -.3973 | -.2176 | -.0474 | -.0483 |
| 7 | .9497 | -.8693 | -.7138 | -.2403 | -.4643 | -.2701 | -.1212 | -.1151 |
| 8 | .8813 | -.7698 | -.5857 | -.0622 | -.4039 | -.3633 | -.2394 | -.1886 |
| 9 | .4068 | -.3527 | -.2415 | -.0015 | -.1849 | -.1484 | -.1611 | -.0174 |
| 10 | 1.0000 | -.9039 | -.7214 | -.1779 | -.4718 | -.3181 | -.1548 | -.1336 |
| 11 | | 1.0000 | .9467 | .1161 | .4222 | .0986 | .0601 | -.0919 |
| 12 | | | 1.0000 | .0774 | .3402 | -.0573 | .0097 | -.2315 |
| 13 | | | | 1.0000 | .4021 | .1175 | .0989 | .1215 |
| 14 | | | | | 1.0000 | -.0230 | -.1018 | .0884 |
| 15 | | | | | | 1.0000 | .8223 | .7023 |
| 16 | | | | | | | 1.0000 | .6584 |

| | $x_{18}$ | $x_{19}$ | $x_{20}$ | $x_{21}$ | $x_{22}$ | $x_{23}$ | $x_{24}$ | $x_{25}$ |
|---|---|---|---|---|---|---|---|---|
| 2 | .6151 | .5657 | .5883 | .8069 | .6728 | .1885 | .5779 | .8138 |
| 3 | -.4523 | -.6096 | -.7437 | -.3642 | -.3405 | -.3752 | -.2022 | -.3488 |
| 4 | -.2231 | .4422 | .6013 | .0703 | .0903 | .3275 | -.0214 | .0103 |
| 5 | -.0653 | -.2097 | -.3271 | -.1330 | -.1676 | -.0144 | -.0871 | -.1544 |
| 6 | -.2685 | -.4410 | -.5911 | -.2754 | -.2371 | -.2357 | -.1490 | -.2855 |
| 7 | -.4107 | -.5689 | -.6825 | -.3275 | -.2722 | -.3530 | -.1705 | -.3329 |
| 8 | -.4960 | -.5718 | -.6775 | -.3904 | -.3641 | -.3810 | -.2307 | -.3370 |
| 9 | -.2250 | -.3552 | -.4157 | -.1335 | -.1771 | -.2315 | -.0624 | -.1142 |
| 10 | -.4507 | -.5977 | -.7325 | -.3719 | -.3378 | -.3655 | -.2086 | -.3587 |
| 11 | .1937 | .4051 | .5668 | .0463 | .0582 | .3075 | -.0383 | -.0155 |
| 12 | -.0081 | .2078 | .3685 | -.1993 | -.1614 | .2441 | -.2082 | -.2805 |
| 13 | .0876 | .1183 | .1671 | .0486 | .0066 | .1541 | .1213 | .2462 |
| 14 | .0552 | .1521 | .2305 | .2896 | .0994 | -.1624 | .2872 | .1603 |
| 15 | .6437 | .0556 | .1935 | .5230 | .5967 | .5934 | .3975 | .4623 |
| 16 | .4332 | -.1072 | .0381 | .3063 | .3558 | .5867 | .3251 | .2641 |
| 17 | .3275 | -.2184 | -.0600 | .6464 | .4703 | .0713 | .7140 | .2915 |

Table 16 (continued). CORRELATION MATRIX OF SURFACE SOIL VARIABLES (coefficient of correlation - r)

| $X_i$<br>i | $X_{18}$ | $X_{19}$ | $X_{20}$ | $X_{21}$ | $X_{22}$ | $X_{23}$ | $X_{24}$ | $X_{25}$ |
|---|---|---|---|---|---|---|---|---|
| 18 | 1.0000 | .4827 | .4557 | .4686 | .6553 | .6244 | .3043 | .7113 |
| 19 | | 1.0000 | .8995 | .1664 | .2488 | .4142 | .0494 | .5586 |
| 20 | | | 1.0000 | .1428 | .2738 | .4808 | .1179 | .4703 |
| 21 | | | | 1.0000 | .6783 | -.0405 | .5725 | .5755 |
| 22 | | | | | 1.0000 | .2553 | .3988 | .5131 |
| 23 | | | | | | 1.0000 | -.0626 | .3530 |
| 24 | | | | | | | 1.0000 | .3937 |
| | $X_{26}$ | $X_{27}$ | $X_{28}$ | $X_{29}$ | $X_{30}$ | $X_{31}$ | $X_{32}$ | $X_{33}$ |
| 2 | .7750 | .6714 | .7344 | .7782 | .4822 | .5746 | -.5021 | .8431 |
| 3 | -.6665 | -.4717 | -.4418 | -.5266 | -.4881 | -.6326 | .7889 | -.5678 |
| 4 | .4570 | .2768 | .2029 | .2664 | .3345 | .4664 | -.7166 | .2608 |
| 5 | -.3766 | -.2534 | -.2271 | -.1413 | -.2400 | -.2263 | .2780 | -.2733 |
| 6 | -.5384 | -.3800 | -.3583 | -.3615 | -.3743 | -.4642 | .7144 | -.4281 |
| 7 | -.6121 | -.4303 | -.4120 | -.4646 | -.4518 | -.5890 | .9382 | -.5106 |
| 8 | -.6118 | -.4514 | -.4254 | -.5239 | -.4409 | -.5909 | .6512 | -.5345 |
| 9 | -.3208 | -.2030 | -.1641 | -.3322 | -.2714 | -.3665 | .1086 | -.3147 |
| 10 | -.6662 | -.4761 | -.4507 | -.5115 | -.4811 | -.6207 | .8393 | -.5598 |
| 11 | .4296 | .2582 | .1857 | .2163 | .3058 | .4293 | -.7662 | .2142 |
| 12 | .1817 | .0566 | -.0384 | -.0187 | .1372 | .2297 | -.6472 | -.0712 |
| 13 | .1632 | .1915 | .0280 | .2740 | -.0167 | .1256 | -.3032 | .1483 |
| 14 | .3762 | .3130 | .2815 | .2606 | .1331 | .1633 | -.4419 | .1836 |
| 15 | .3641 | .4350 | .3421 | .6492 | .0591 | .0731 | -.3385 | .2855 |
| 16 | .0710 | .2804 | .0533 | .5085 | -.1621 | -.0906 | -.2572 | .0351 |
| 17 | .4016 | .6505 | .4805 | .4686 | -.1726 | -.2014 | -.1878 | .1108 |
| 18 | .3380 | .3333 | .2931 | .5395 | .2456 | .4846 | -.4017 | .6353 |
| 19 | .3666 | .0920 | .2106 | .3066 | .7468 | .9986 | -.4731 | .8625 |
| 20 | .5279 | .2727 | .2420 | .3916 | .6648 | .9216 | -.5644 | .7945 |
| 21 | .6702 | .7022 | .8114 | .6916 | .1004 | .1653 | -.3101 | .4657 |
| 22 | .6302 | .6899 | .6162 | .5431 | .0261 | .2545 | -.2173 | .5019 |
| 23 | .0409 | -.0253 | -.2035 | .3790 | .2781 | .4269 | -.3976 | .3363 |
| 24 | .3906 | .6313 | .4207 | .3237 | -.0755 | .0583 | -.1688 | .3223 |
| 25 | .3640 | .2740 | .3505 | .6972 | .4384 | .5539 | -.3259 | .8378 |
| 26 | 1.0000 | .7908 | .7262 | .5841 | .2768 | .3903 | -.4690 | .5328 |
| 27 | | 1.0000 | .7303 | .5285 | -.1327 | .1151 | -.3672 | .3188 |
| 28 | | | 1.0000 | .5025 | .0987 | .2167 | -.3441 | .4387 |
| 29 | | | | 1.0000 | -.2950 | .3203 | -.4686 | .5528 |
| 30 | | | | | 1.0000 | .7449 | -.3792 | .6953 |
| 31 | | | | | | 1.0000 | -.4894 | .8636 |
| 32 | | | | | | | 1.0000 | -.4113 |
| 33 | | | | | | | | 1.0000 |

Table 16 (continued). CORRELATION MATRIX OF SURFACE SOIL VARIABLES
(coefficient of correlation - r)

| $X_i$<br>i | $X_{34}$ | $X_{35}$ | $X_{36}$ | $X_{37}$ | $X_{38}$ | $X_{39}$ | Knomo | Kobs |
|---|---|---|---|---|---|---|---|---|
| 2 | .7314 | .8966 | .7048 | .8648 | -.5688 | .1371 | -.0215 | .0564 |
| 3 | -.5186 | -.5005 | -.3747 | -.5343 | .9196 | -.8474 | -.6229 | -.6801 |
| 4 | .2772 | .1750 | .1372 | .2510 | -.8497 | .9761 | .7828 | .8179 |
| 5 | -.2623 | -.1907 | -.1763 | -.2741 | .6158 | -.5044 | -.4414 | -.4408 |
| 6 | -.4011 | -.3631 | -.2906 | -.4297 | .8922 | -.6968 | -.6397 | -.6393 |
| 7 | -.4757 | -.4291 | -.3368 | -.4934 | .9847 | -.7876 | -.7103 | -.7167 |
| 8 | -.4933 | -.5050 | -.3824 | -.5141 | .7197 | -.7499 | -.4210 | -.5220 |
| 9 | -.2405 | -.2840 | -.1405 | -.2142 | .2435 | -.4167 | -.1878 | -.2606 |
| 10 | -.5200 | -.4922 | -.3820 | -.5421 | .9565 | -.8454 | -.6436 | -.6923 |
| 11 | .2498 | .1267 | .1186 | .2271 | -.8816 | .9807 | .8208 | .8425 |
| 12 | .0105 | -.1544 | -.0907 | -.0388 | -.7239 | .9503 | .8592 | .8577 |
| 13 | .0234 | .1651 | .0215 | .1333 | -.2385 | .0507 | .3632 | .3324 |
| 14 | .1878 | .2042 | .2398 | .3382 | -.4634 | .3887 | .5615 | .6379 |
| 15 | .1829 | .7705 | .5037 | .4609 | -.2413 | .0142 | -.2149 | -.0906 |
| 16 | -.1015 | .5793 | .2615 | .1907 | -.0787 | -.0067 | -.2000 | -.1074 |
| 17 | .1825 | .7103 | .6432 | .6130 | -.0903 | -.1582 | -.3094 | -.1658 |
| 18 | .3837 | .6491 | .3117 | .4290 | -.3795 | .1218 | -.0781 | -.0357 |
| 19 | .6027 | .3262 | .0615 | .2837 | -.5488 | .3712 | .2374 | .1930 |
| 20 | .5579 | .4150 | .1243 | .3641 | -.6734 | .5363 | .3653 | .3516 |
| 21 | .6083 | .7969 | .8459 | .8606 | -.3186 | -.0353 | -.1839 | -.0700 |
| 22 | .5416 | .7175 | .6601 | .7202 | -.2761 | -.0032 | -.1782 | -.0980 |
| 23 | -.0247 | .3414 | -.1479 | -.0632 | -.3179 | .2532 | .0969 | .0916 |
| 24 | .2203 | .6575 | .5316 | .6168 | -.1695 | -.0876 | -.1674 | -.0459 |
| 25 | .4528 | .7685 | .3334 | .4943 | -.3275 | -.1215 | -.1890 | -.1839 |
| 26 | .6274 | .6650 | .6878 | .8244 | -.6203 | .3882 | .2216 | .3150 |
| 27 | .5199 | .6800 | .7643 | .8877 | -.4340 | .2072 | .0733 | .1790 |
| 28 | .8589 | .6216 | .9591 | .9351 | -.4124 | .1298 | -.0018 | .1199 |
| 29 | .4002 | .8293 | .5471 | .6283 | -.4424 | .1187 | -.0056 | .0570 |
| 30 | .4033 | .2449 | -.0322 | .1247 | -.4503 | .2661 | .1394 | .1112 |
| 31 | .6038 | .3406 | .0698 | .2966 | -.5700 | .3954 | .2556 | .2145 |
| 32 | -.3784 | -.4048 | -.2973 | -.4231 | .8920 | -.6467 | -.6540 | -.6553 |
| 33 | .7045 | .6588 | .3410 | .5554 | -.5094 | .1469 | .0002 | .0062 |
| 34 | 1.0000 | .5007 | .7278 | .7899 | -.4761 | .2012 | .0595 | .1167 |
| 35 |  | 1.0000 | .7068 | .7891 | -.4205 | .0324 | -.1821 | -.0671 |
| 36 |  |  | 1.0000 | .9237 | -.3353 | .0583 | -.1023 | .0548 |
| 37 |  |  |  | 1.0000 | -.4943 | .1554 | .0035 | .1226 |
| 38 |  |  |  |  | 1.0000 | -.8021 | -.7208 | -.7264 |
| 39 |  |  |  |  |  | 1.0000 | .7991 | .8251 |
| Knomo |  |  |  |  |  |  | 1.0000 | .9555 |
| Kobs |  |  |  |  |  |  |  | 1.0000 |

## Table 17. CORRELATION MATRIX OF SUBSOIL VARIABLES (coefficient of correlation - r)

| $X_i$<br>i | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ |
|---|---|---|---|---|---|---|---|---|
| 2 | 1.0000 | -.8208 | .1080 | -.7942 | -.8072 | -.7957 | -.8087 | -.8177 |
| 3 |  | 1.0000 | -.6513 | .9098 | .9956 | .9950 | .9955 | .9615 |
| 4 |  |  | 1.0000 | -.5174 | -.6619 | -.6711 | -.6523 | -.6062 |
| 5 |  |  |  | 1.0000 | .9073 | .8871 | .9384 | .7812 |
| 6 |  |  |  |  | 1.0000 | .9975 | .9910 | .9466 |
| 7 |  |  |  |  |  | 1.0000 | .9890 | .9534 |
| 8 |  |  |  |  |  |  | 1.0000 | .9338 |

|  | $X_{10}$ | $X_{11}$ | $X_{12}$ | $X_{13}$ | $X_{14}$ | $X_{15}$ | $X_{16}$ | $X_{17}$ |
|---|---|---|---|---|---|---|---|---|
| 2 | -.8077 | -.2879 | -.7977 | a | a | .6722 | .8139 | .0668 |
| 3 | .9957 | -.3032 | .3257 | a | a | -.3275 | -.5760 | -.1109 |
| 4 | -.6552 | .9127 | .5030 | a | a | -.3885 | -.1299 | .0225 |
| 5 | .9373 | -.2321 | .3759 | a | a | -.3959 | -.5405 | -.4380 |
| 6 | .9949 | -.3238 | .3014 | a | a | -.3218 | -.5858 | -.0852 |
| 7 | .9918 | -.3316 | .2915 | a | a | -.3311 | -.5954 | -.0734 |
| 8 | .9991 | -.3187 | .3165 | a | a | -.3477 | -.5727 | -.1970 |
| 9 | .9320 | -.2282 | .3530 | a | a | -.2660 | -.5404 | .0952 |
| 10 | 1.0000 | -.3232 | .3109 | a | a | -.3425 | -.5779 | -.1781 |
| 11 |  | 1.0000 | .7971 | a | a | -.6123 | -.4368 | .0764 |
| 12 |  |  | 1.0000 | a | a | -.3386 | -.7990 | -.0925 |
| 13 |  |  |  | a | a | a | a | a |
| 14 |  |  |  |  | a | a | a | a |
| 15 |  |  |  |  |  | 1.0000 | .9093 | .2669 |
| 16 |  |  |  |  |  |  | 1.0000 | .0711 |

|  | $X_{18}$ | $X_{19}$ | $X_{20}$ | $X_{21}$ | $X_{22}$ | $X_{23}$ | $X_{24}$ | $X_{25}$ |
|---|---|---|---|---|---|---|---|---|
| 2 | .2299 | -.1142 | -.1872 | .3952 | .4175 | .5925 | .7584 | .6367 |
| 3 | -.2092 | -.0967 | -.3392 | -.1860 | -.3784 | -.3463 | -.5708 | -.6496 |
| 4 | .0748 | .4353 | .8099 | -.3006 | .0581 | -.1274 | -.0849 | .3594 |
| 5 | -.3739 | .1029 | -.1748 | -.2320 | -.4878 | -.0863 | -.6532 | -.5250 |
| 6 | -.1582 | -.0826 | -.3306 | -.1473 | -.3050 | -.3571 | -.5534 | -.6058 |
| 7 | -.1468 | -.0722 | -.3710 | -.1737 | -.3185 | -.3598 | -.5552 | -.5997 |
| 8 | -.2558 | -.0408 | -.3527 | -.2071 | -.4233 | -.2683 | -.5917 | -.6214 |
| 9 | -.1444 | -.2545 | -.3157 | -.1658 | -.3347 | -.5156 | -.4975 | -.7441 |
| 10 | -.2274 | -.0421 | -.3412 | -.1895 | -.3866 | -.2834 | -.5855 | -.6068 |
| 11 | .0175 | .4021 | .8291 | -.4533 | -.1009 | -.4209 | -.3596 | .0577 |
| 12 | -.1515 | .4028 | .6107 | -.6098 | -.3901 | -.5581 | -.7571 | -.3171 |
| 13 | a | a | a | a | a | a | a | a |
| 14 | a | a | a | a | a | a | a | a |
| 15 | .1754 | -.7333 | -.3058 | .6850 | .4344 | .3150 | .7789 | .0838 |
| 16 | -.0689 | -.5639 | -.2223 | .6195 | .2496 | .5454 | .8304 | .1679 |
| 17 | .4510 | -.5731 | .0708 | .4969 | .6598 | -.7284 | .4855 | -.1839 |

Table 17 (continued). CORRELATION MATRIX OF SUBSOIL VARIABLES
(coefficient of correlation - r)

| $X_i$ i | $X_{18}$ | $X_{19}$ | $X_{20}$ | $X_{21}$ | $X_{22}$ | $X_{23}$ | $X_{24}$ | $X_{25}$ |
|---|---|---|---|---|---|---|---|---|
| 18 | 1.0000 | .0692 | .2065 | -.0588 | .7571 | -.3335 | .0165 | .5931 |
| 19 | | 1.0000 | .2402 | -.7033 | -.2438 | .2427 | -.6116 | .5581 |
| 20 | | | 1.0000 | -.1739 | .2244 | -.3458 | -.2327 | .1940 |
| 21 | | | | 1.0000 | .5613 | .0170 | .8505 | .1584 |
| 22 | | | | | 1.0000 | -.2811 | .5173 | .4589 |
| 23 | | | | | | 1.0000 | .2107 | .4213 |
| 24 | | | | | | | 1.0000 | .0973 |
| | $X_{26}$ | $X_{27}$ | $X_{28}$ | $X_{29}$ | $X_{30}$ | $X_{31}$ | $X_{32}$ | $X_{33}$ |
| 2 | .8904 | .8554 | .7571 | .7660 | .9109 | -.1237 | -.7768 | .5699 |
| 3 | -.6985 | -.7438 | -.6262 | -.5124 | -.6491 | -.1158 | .9674 | -.6883 |
| 4 | .0231 | .1354 | .0310 | -.1001 | -.0424 | .4776 | -.6428 | .5353 |
| 5 | -.8104 | -.8803 | -.6492 | -.5687 | -.5055 | .0906 | .9717 | -.5319 |
| 6 | -.7168 | -.7605 | -.6457 | -.4610 | -.6367 | -.1015 | .9690 | -.6689 |
| 7 | -.6884 | -.7349 | -.6404 | -.4492 | -.6320 | -.0936 | .9601 | -.6508 |
| 8 | -.7126 | -.7715 | -.6287 | -.5191 | -.6030 | -.0616 | .9851 | -.6436 |
| 9 | -.5899 | -.6013 | -.5506 | -.5286 | -.7451 | -.2696 | .8644 | -.7860 |
| 10 | -.7229 | -.7789 | -.6407 | -.4981 | -.6057 | -.0622 | .9854 | -.6437 |
| 11 | -.2747 | -.1431 | -.2450 | -.3940 | -.4348 | .4461 | -.3428 | .2514 |
| 12 | -.7329 | -.6433 | -.6561 | -.7210 | -.7979 | .4335 | .2866 | -.1369 |
| 13 | a | a | a | a | a | a | a | a |
| 14 | a | a | a | a | a | a | a | a |
| 15 | .7177 | .6975 | .6853 | .5706 | .5813 | -.7399 | -.3563 | -.1870 |
| 16 | .8225 | .7877 | .8729 | .4717 | .7455 | -.5682 | -.5465 | .0537 |
| 17 | .2362 | .3672 | .2226 | .1974 | -.3181 | -.5594 | -.2926 | -.3282 |
| 18 | .1540 | .2335 | -.2808 | .7394 | .0725 | .0807 | -.3265 | .2541 |
| 19 | -.3614 | -.4003 | -.5192 | -.0007 | .0785 | .9982 | .0189 | .7380 |
| 20 | -.3198 | -.1784 | -.2604 | -.1563 | -.2928 | .2973 | -.3396 | .1569 |
| 21 | .3300 | .3429 | .6317 | .2589 | .2503 | -.7024 | -.1604 | -.3239 |
| 22 | .2462 | .3352 | .1335 | .7209 | .1915 | -.2261 | -.4295 | .1222 |
| 23 | .4052 | .2564 | .4082 | .2968 | .8549 | .2176 | -.1624 | .4967 |
| 24 | .7588 | .7671 | .9007 | .4639 | .5458 | -.6157 | -.5726 | .0198 |
| 25 | .3349 | .3219 | .0106 | .7890 | .6669 | .5608 | -.5758 | .8836 |
| 26 | 1.0000 | .9820 | .8330 | .5911 | .7188 | -.3750 | -.7471 | .3158 |
| 27 | | 1.0000 | .8139 | .5765 | .6212 | -.4047 | -.8208 | .2852 |
| 28 | | | 1.0000 | .2449 | .5997 | -.5266 | -.6085 | .0907 |
| 29 | | | | 1.0000 | .7003 | -.0102 | -.5186 | .4974 |
| 30 | | | | | 1.0000 | .0593 | -.5293 | .6148 |
| 31 | | | | | | 1.0000 | -.0022 | .7355 |
| 32 | | | | | | | 1.0000 | -.5864 |

Table 17 (continued). CORRELATION MATRIX OF SUBSOIL VARIABLES
(coefficient of correlation - r)

| $X_i$ / i | $X_{34}$ | $X_{35}$ | $X_{36}$ | $X_{37}$ | Knomo | Kobs |
|---|---|---|---|---|---|---|
| 2 | .6723 | .8424 | .8040 | .8831 | -.7682 | -.7842 |
| 3 | -.7675 | -.5173 | -.5136 | -.7386 | .3271 | .4579 |
| 4 | .4886 | -.2385 | -.2132 | .0758 | .4850 | .2054 |
| 5 | -.6072 | -.4252 | -.4345 | -.7716 | .4431 | .3101 |
| 6 | -.7846 | -.5179 | -.5199 | -.7503 | .3058 | .4238 |
| 7 | -.7690 | -.5257 | -.5309 | -.7397 | .2966 | .4216 |
| 8 | -.7202 | -.4917 | -.4948 | -.7425 | .3397 | .4026 |
| 9 | -.8165 | -.5543 | -.5254 | -.6633 | .2951 | .6108 |
| 10 | -.7378 | -.4560 | -.5007 | -.7511 | .3322 | .3986 |
| 11 | .1785 | -.5768 | -.5310 | -.2481 | .7453 | .5653 |
| 12 | -.2673 | -.8782 | -.8392 | -.7283 | .9703 | .8071 |
| 13 | a | a | a | a | a | a |
| 14 | a | a | a | a | a | a |
| 15 | .0277 | .8570 | .8749 | .7270 | -.9177 | -.4557 |
| 16 | .4085 | .9536 | .9819 | .8976 | -.8277 | -.5917 |
| 17 | -.2943 | -.1435 | -.0655 | .2299 | -.2867 | .3037 |
| 18 | -.3000 | -.0700 | -.1557 | -.0768 | -.2401 | .0253 |
| 19 | .3515 | -.3772 | -.4863 | -.4313 | .5728 | -.1317 |
| 20 | -.0205 | -.3453 | -.3113 | -.2384 | .5413 | .4297 |
| 21 | -.0053 | .5356 | .6131 | .5643 | -.6740 | -.3824 |
| 22 | -.1511 | .1946 | .1775 | .2541 | -.4856 | -.2204 |
| 23 | .6385 | .7390 | .6673 | .4475 | -.3796 | -.8177 |
| 24 | .3828 | .7329 | .7927 | .9010 | -.8160 | -.5390 |
| 25 | .4653 | .3090 | .1820 | .2233 | -.2266 | -.5823 |
| 26 | .5581 | .7660 | .7661 | .9262 | -.7719 | -.5183 |
| 27 | .5088 | .6849 | .6999 | .9100 | -.7185 | -.3969 |
| 28 | .6118 | .7754 | .8461 | .9703 | -.6825 | -.5148 |
| 29 | .1785 | .5586 | .4568 | .4497 | -.7159 | -.6279 |
| 30 | .6696 | .8803 | .8048 | .7163 | -.6874 | -.9161 |
| 31 | .3445 | -.3921 | -.4973 | -.4387 | .5965 | -.1033 |
| 32 | -.6494 | -.4371 | -.4444 | -.7307 | .3407 | .2954 |
| 33 | .7513 | .1914 | .0872 | .2505 | -.0001 | -.5543 |
| 34 | 1.0000 | .4544 | .4425 | .6469 | -.1473 | -.6065 |
| 35 |  | 1.0000 | .9854 | .8226 | -.8419 | -.7743 |
| 36 |  |  | 1.0000 | .8613 | -.8261 | -.6991 |
| 37 |  |  |  | 1.0000 | -.7523 | -.5908 |
| Knomo |  |  |  |  | 1.0000 | .6556 |
| Kobs |  |  |  |  |  | 1.0000 |

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[a] Coefficient of correlation could not be computed because of missing data.